DAQ

NI 4472 User Manual

Dynamic Signal Acquisition Device for PXI™/CompactPCI

NATIONAL INSTRUMENTS™

January 2001 Edition
Part Number 322940A-01

Worldwide Technical Support and Product Information

ni.com

National Instruments Corporate Headquarters

11500 North Mopac Expressway Austin, Texas 78759-3504 USA Tel: 512 794 0100

Worldwide Offices

Australia 03 9879 5166, Austria 0662 45 79 90 0, Belgium 02 757 00 20, Brazil 011 284 5011, Canada (Calgary) 403 274 9391, Canada (Ottawa) 613 233 5949, Canada (Québec) 514 694 8521, China (Shanghai) 021 6555 7838, China (ShenZhen) 0755 3904939, Denmark 45 76 26 00, Finland 09 725 725 11, France 01 48 14 24 24, Germany 089 741 31 30, Greece 30 1 42 96 427, Hong Kong 2645 3186, India 91805275406, Israel 03 6120092, Italy 02 413091, Japan 03 5472 2970, Korea 02 596 7456, Mexico 5 280 7625, Netherlands 0348 433466, New Zealand 09 914 0488, Norway 32 27 73 00, Poland 0 22 528 94 06, Portugal 351 1 726 9011, Singapore 2265886, Spain 91 640 0085, Sweden 08 587 895 00, Switzerland 056 200 51 51, Taiwan 02 2528 7227, United Kingdom 01635 523545

For further support information, see the *Technical Support Resources* appendix. To comment on the documentation, send e-mail to techpubs@ni.com

Important Information

Warranty

The NI 4472 for PXI/CompactPCI 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.

National Instruments believes that the information in this document is accurate. The document has been carefully reviewed for technical accuracy. In the event that technical or typographical errors exist, National Instruments reserves the right to make changes to subsequent editions of this document without prior notice to holders of this edition. The reader should consult National Instruments if errors are suspected. In no event shall National Instruments be liable for any damages arising out of or related to this document or the information contained in it.

EXCEPT AS SPECIFIED HEREIN, NATIONAL INSTRUMENTS MAKES NO WARRANTIES, EXPRESS OR IMPLIED, AND SPECIFICALLY DISCLAIMS ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. CUSTOMER'S RIGHT TO RECOVER DAMAGES CAUSED BY FAULT OR NEGLIGENCE ON THE PART OF NATIONAL INSTRUMENTS SHALL BE LIMITED TO THE AMOUNT THERETOFORE PAID BY THE CUSTOMER. NATIONAL INSTRUMENTS WILL NOT BE LIABLE FOR DAMAGES RESULTING FROM LOSS OF DATA, PROFITS, USE OF PRODUCTS, OR INCIDENTAL OR CONSEQUENTIAL DAMAGES, EVEN IF ADVISED OF THE POSSIBILITY THEREOF. This limitation of the liability of National Instruments will apply regardless of the form of action, whether in contract or tort, including negligence. Any action against National Instruments must be brought within one year after the cause of action accrues. National Instruments shall not be liable for any delay in performance due to causes beyond its reasonable control. The warranty provided herein does not cover damages, defects, malfunctions, or service failures caused by owner's failure to follow the National Instruments installation, operation, or maintenance instructions; owner's modification of the product; owner's abuse, misuse, or negligent acts; and power failure or surges, fire, flood, accident, actions of third parties, or other events outside reasonable control.

Trademarks

ComponentWorks™, CVI™, DAQ-STC™, LabVIEW™, Measurement Studio™, MITE™, National Instruments™, ni.com™, NI-DAQ™, PXI™, RTSI™, and SCXI™ are trademarks of National Instruments Corporation.

ICP is a registered trademark of PCB Piezotronics, Inc. Other product and company names mentioned herein are trademarks or trade names of their respective companies.

WARNING REGARDING USE OF NATIONAL INSTRUMENTS PRODUCTS

(1) NATIONAL INSTRUMENTS PRODUCTS ARE NOT DESIGNED WITH COMPONENTS AND TESTING FOR A LEVEL OF RELIABILITY SUITABLE FOR USE IN OR IN CONNECTION WITH SURGICAL IMPLANTS OR AS CRITICAL COMPONENTS IN ANY LIFE SUPPORT SYSTEMS WHOSE FAILURE TO PERFORM CAN REASONABLY BE EXPECTED TO CAUSE SIGNIFICANT INJURY TO A HUMAN.

(2) IN ANY APPLICATION, INCLUDING THE ABOVE, RELIABILITY OF OPERATION OF THE SOFTWARE PRODUCTS CAN BE IMPAIRED BY ADVERSE FACTORS, INCLUDING BUT NOT LIMITED TO FLUCTUATIONS IN ELECTRICAL POWER SUPPLY, COMPUTER HARDWARE MALFUNCTIONS, COMPUTER OPERATING SYSTEM SOFTWARE FITNESS, FITNESS OF COMPILERS AND DEVELOPMENT SOFTWARE USED TO DEVELOP AN APPLICATION, INSTALLATION ERRORS, SOFTWARE AND HARDWARE COMPATIBILITY PROBLEMS, MALFUNCTIONS OR FAILURES OF ELECTRONIC MONITORING OR CONTROL DEVICES, TRANSIENT FAILURES OF ELECTRONIC SYSTEMS (HARDWARE AND/OR SOFTWARE), UNANTICIPATED USES OR MISUSES, OR ERRORS ON THE PART OF THE USER OR APPLICATIONS DESIGNER (ADVERSE FACTORS SUCH AS THESE ARE HEREAFTER COLLECTIVELY TERMED "SYSTEM FAILURES"). ANY APPLICATION WHERE A SYSTEM FAILURE WOULD CREATE A RISK OF HARM TO PROPERTY OR PERSONS (INCLUDING THE RISK OF BODILY INJURY AND DEATH) SHOULD NOT BE RELIANT SOLELY UPON ONE FORM OF ELECTRONIC SYSTEM DUE TO THE RISK OF SYSTEM FAILURE. TO AVOID DAMAGE, INJURY, OR DEATH, THE USER OR APPLICATION DESIGNER MUST TAKE REASONABLY PRUDENT STEPS TO PROTECT AGAINST SYSTEM FAILURES, INCLUDING BUT NOT LIMITED TO BACK-UP OR SHUT DOWN MECHANISMS. BECAUSE EACH END-USER SYSTEM IS CUSTOMIZED AND DIFFERS FROM NATIONAL INSTRUMENTS' TESTING PLATFORMS AND BECAUSE A USER OR APPLICATION DESIGNER MAY USE NATIONAL INSTRUMENTS PRODUCTS IN COMBINATION WITH OTHER PRODUCTS IN A MANNER NOT EVALUATED OR CONTEMPLATED BY NATIONAL INSTRUMENTS, THE USER OR APPLICATION DESIGNER IS ULTIMATELY RESPONSIBLE FOR VERIFYING AND VALIDATING THE SUITABILITY OF NATIONAL INSTRUMENTS PRODUCTS WHENEVER NATIONAL INSTRUMENTS PRODUCTS ARE INCORPORATED IN A SYSTEM OR APPLICATION, INCLUDING, WITHOUT LIMITATION, THE APPROPRIATE DESIGN, PROCESS AND SAFETY LEVEL OF SUCH SYSTEM OR APPLICATION.

Compliance

FCC/Canada Radio Frequency Interference Compliance*

Determining FCC Class

The Federal Communications Commission (FCC) has rules to protect wireless communications from interference. The FCC places digital electronics into two classes. These classes are known as Class A (for use in industrial-commercial locations only) or Class B (for use in residential or commercial locations). Depending on where it is operated, this product could be subject to restrictions in the FCC rules. (In Canada, the Department of Communications (DOC), of Industry Canada, regulates wireless interference in much the same way.)

Digital electronics emit weak signals during normal operation that can affect radio, television, or other wireless products. By examining the product you purchased, you can determine the FCC Class and therefore which of the two FCC/DOC Warnings apply in the following sections. (Some products may not be labeled at all for FCC; if so, the reader should then assume these are Class A devices.)

FCC Class A products only display a simple warning statement of one paragraph in length regarding interference and undesired operation. Most of our products are FCC Class A. The FCC rules have restrictions regarding the locations where FCC Class A products can be operated.

FCC Class B products display either a FCC ID code, starting with the letters **EXN**, or the FCC Class B compliance mark that appears as shown here on the right.

Trade Name Model Number
Tested to Comply with FCC Standards
FOR HOME OR OFFICE USE

Consult the FCC web site `http://www.fcc.gov` for more information.

FCC/DOC Warnings

This equipment generates and uses radio frequency energy and, if not installed and used in strict accordance with the instructions in this manual and the CE Mark Declaration of Conformity**, may cause interference to radio and television reception. Classification requirements are the same for the Federal Communications Commission (FCC) and the Canadian Department of Communications (DOC).

Changes or modifications not expressly approved by National Instruments could void the user's authority to operate the equipment under the FCC Rules.

Class A

Federal Communications Commission

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Canadian Department of Communications

This Class A digital apparatus meets all requirements of the Canadian Interference-Causing Equipment Regulations.

Cet appareil numérique de la classe A respecte toutes les exigences du Règlement sur le matériel brouilleur du Canada.

Class B

Federal Communications Commission

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

Canadian Department of Communications

This Class B digital apparatus meets all requirements of the Canadian Interference-Causing Equipment Regulations.

Cet appareil numérique de la classe B respecte toutes les exigences du Règlement sur le matériel brouilleur du Canada.

European Union - Compliance to EEC Directives

Readers in the EU/EEC/EEA must refer to the Manufacturer's Declaration of Conformity (DoC) for information** pertaining to the CE Mark compliance scheme. The Manufacturer includes a DoC for most every hardware product except for those bought for OEMs, if also available from an original manufacturer that also markets in the EU, or where compliance is not required as for electrically benign apparatus or cables.

* Certain exemptions may apply in the USA, see FCC Rules §15.103 **Exempted devices**, and §15.105(c). Also available in sections of CFR 47.

** The CE Mark Declaration of Conformity will contain important supplementary information and instructions for the user or installer.

Conventions

The following conventions are used in this manual:

<> — Angle brackets that contain numbers separated by an ellipsis represent a range of values associated with a bit or signal name—for example, CH<0..7>.

» — The » symbol leads you through nested menu items and dialog box options to a final action. The sequence **File»Page Setup»Options** directs you to pull down the **File** menu, select the **Page Setup** item, and select **Options** from the last dialog box.

This icon denotes a tip, which alerts you to advisory information.

This icon denotes a note, which alerts you to important information.

This icon denotes a caution, which advises you of precautions to take to avoid injury, data loss, or a system crash.

bold — Bold text denotes items that you must select or click on in the software, such as menu items and dialog box options. Bold text also denotes parameter names.

italic — Italic text denotes variables, emphasis, a cross reference, or an introduction to a key concept. This font also denotes text that is a placeholder for a word or value that you must supply.

`monospace` — Text in this font is used for the proper names of paths, directories, and filenames.

`monospace bold` — Bold text in this font denotes the messages and responses that the computer automatically prints to the screen.

Contents

Chapter 1
Getting Started with Your NI 4472 for PXI/CompactPCI

Chapter 2
Using Your NI 4472

Chapter 3
Device Overview and Theory of Operation

Chapter 4 Calibration

Appendix A Specifications

Appendix B Technical Support Resources

Glossary

Index

1

Getting Started with Your NI 4472 for PXI/CompactPCI

This chapter describes the NI 4472 for PXI/CompactPCI, lists what you need to get started, explains how to unpack your device, and describes your programming choices.

About the NI 4472

The NI 4472 is a high-performance, high-accuracy analog input device for the PXI or CompactPCI bus. It is part of the National Instruments Dynamic Signal Acquisition/Analysis (DSA) product family and is specifically designed for demanding dynamic signal acquisition applications. The NI 4472 features eight analog input channels simultaneously sampled at a maximum rate of 102.4 kS/s with 24-bit resolution and multiple triggering modes, including external digital triggering. Each input channel has an independent software-switchable 4 mA current source for Integrated Circuit Piezoelectric (ICP®)-type accelerometers and microphone preamplifiers. See Appendix A, *Specifications*, for details about your NI 4472.

The analog input circuitry uses oversampling delta-sigma modulating analog-to-digital converters (ADCs). Delta-sigma converters are inherently linear, provide built-in brick-wall anti-aliasing filters, and have specifications that exceed other conventional technology for this application with regard to total harmonic distortion (THD), signal-to-noise ratio (SNR), and amplitude flatness. These high-quality specifications and features help you acquire signals with high accuracy and high fidelity without introducing noise or out-of-band aliases.

Applications for NI 4472 devices include audio signal processing and analysis, acoustics and speech research, sonar, audio frequency test and measurement, vibration and modal analysis, or any application requiring high-fidelity signal acquisition.

What You Need to Get Started

To set up and use your NI 4472 device, you need the following:

- ❑ Your NI 4472 for PXI/CompactPCI DSA device
- ❑ *NI 4472 User Manual*
- ❑ One of the following software packages and documentation:
  - LabVIEW for Windows
  - Measurement Studio
  - A supported application development environment, such as Visual C++
- ❑ NI-DAQ for PC Compatibles and documentation
- ❑ Your PXI/CompactPCI chassis and controller
- ❑ SMB connector cables

The following documents also contain information you may find helpful:

- National Instruments Application Note 025, *Field Wiring and Noise Considerations for Analog Signals*
- National Instruments *PXI Specification*, rev. 1.0
- *PICMG CompactPCI 2.0 R2.1* core specification
- Your PXI/CompactPCI chassis technical reference manual

For free downloads of the latest documentation, drivers, and programming examples, visit `ni.com`

Unpacking

Your NI 4472 is shipped in an antistatic plastic package to prevent electrostatic damage to the device. Electrostatic discharge can damage several components on the device. To avoid such damage when handling the device, take the following precautions:

- Ground yourself with a grounding strap or by holding a grounded object.
- Touch the antistatic package to a metal part of your computer chassis before removing the device from the package.

Caution *Never* touch the exposed pins of connectors.

Remove the device from the package and inspect the device for loose components or any other sign of damage. Notify National Instruments if the device appears damaged in any way. Do *not* install a damaged device into your computer.

Store your NI 4472 in the antistatic envelope when not in use.

Software Programming Choices

When programming your National Instruments DAQ hardware, you can use National Instruments application software or another application development environment (ADE).

National Instruments Application Software

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 virtual instruments for using LabVIEW with National Instruments DAQ hardware, is included with LabVIEW. The LabVIEW Data Acquisition VI Library is functionally equivalent to NI-DAQ software.

Measurement Studio includes LabWindows/CVI, which features interactive graphics and state-of-the-art user interface, and uses the ANSI standard C programming language. The LabWindows/CVI Data Acquisition Library, a series of functions for using National Instruments DAQ hardware, is included with LabWindows/CVI. The LabWindows/CVI Data Acquisition Library is included with the NI-DAQ software.

Measurement Studio also includes ComponentWorks, which contains tools for data acquisition and instrument control built on NI-DAQ driver software. ComponentWorks provides a higher-level programming interface for building virtual instruments through standard OLE controls and DLLs. With ComponentWorks, you can use all of the configuration tools, resource management utilities, and interactive control utilities included with NI-DAQ.

Using LabVIEW or Measurement Studio software greatly reduces the development time for your data acquisition and control application.

NI-DAQ Driver Software

The NI-DAQ driver software shipped with your NI 4472 has an extensive library of functions that you can call from your application programming environment. These functions allow you to use all features of your NI 4472.

NI-DAQ carries out many of the complex interactions between the computer and the DAQ hardware such as handling programming interrupts. NI-DAQ maintains a consistent software interface among its different versions so that you can change platforms with minimal modifications to your code. Whether you are using LabVIEW, Measurement Studio, or other programming languages, your application uses the NI-DAQ driver software, as illustrated in Figure 1-1.

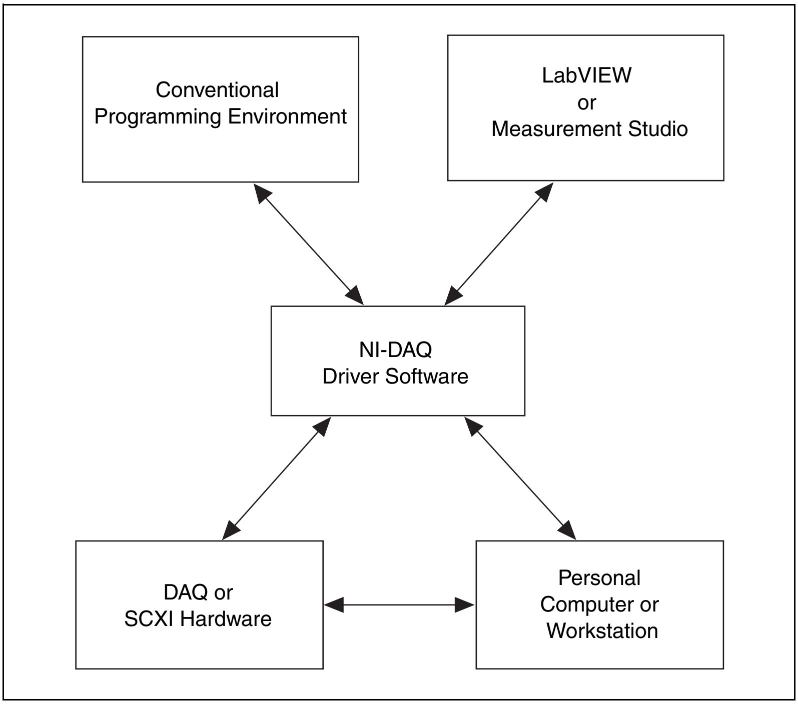

Figure 1-1. The Relationship between the Programming Environment, NI-DAQ, and Your Hardware

To download a free copy of the most recent version of NI-DAQ, click **Download Software** at `ni.com`

Using PXI with CompactPCI

Using PXI-compatible products with standard CompactPCI products is an important feature provided by the *PXI Specification,* rev. 1.0. If you use a PXI-compatible plug-in device in a standard CompactPCI chassis, you will be unable to use PXI-specific functions, but you can still use the basic plug-in device functions. For example, the RTSI bus on your NI 4472 is available in a PXI chassis, but not in a CompactPCI chassis.

Note The CompactPCI specification does not require the chassis to supply +3.3 V to the modules, but the NI 4472 requires +3.3 V power on the PCI bus in order to work. Refer to Appendix A, *Specifications*, for complete power requirements.

The CompactPCI specification permits vendors to develop sub-buses that coexist with the basic PCI interface on the CompactPCI bus. Compatible operation is not guaranteed between CompactPCI devices with different sub-buses nor between CompactPCI devices with sub-buses and PXI. The standard implementation for CompactPCI does not include these sub-buses. Your NI 4472 will work in any standard CompactPCI chassis adhering to the *PICMG CompactPCI 2.0 R2.1* specification.

Caution Damage to your equipment can occur if the lines shown in Table 1-1 are driven by a CompactPCI sub-bus.

PXI-specific features are implemented on the J2 connector of the CompactPCI bus. Table 1-1 lists the J2 pins used by your NI 4472. Your PXI device is compatible with any CompactPCI chassis with a sub-bus that does not drive these lines. Even if the sub-bus is capable of driving these lines, the PXI device is still compatible as long as those pins on the sub-bus are disabled by default and not ever enabled. Damage may result if these lines are driven by the sub-bus.

Table 1-1. J2 Connector Pins Used by the NI 4472

NI 4472 Signal	PXI Pin Name	PXI J2 Pin Number
Master Clock Distribution	PXI Star <0..12>	C20, E20, A19, C19, D19, E19, D15, D2, E2, A1, C1, D1, E1
Sync Pulse	PXI Trigger (5)	C18
Reserved	LBR (7, 8, 10, 11, 12)	A3, C3, E3, A2, B2

Safety Information

Cautions Do *not* operate the device in an explosive atmosphere or where there may be flammable gases or fumes.

Do *not* operate damaged equipment. The safety protection features built into this device can become impaired if the device becomes damaged in any way. If the device is damaged, turn the device off and do *not* use it until service-trained personnel can check its safety. If necessary, return the device to National Instruments for service and repair to ensure that its safety is not compromised.

Do *not* operate this equipment in a manner that contradicts the information specified in this document. Misuse of this equipment could result in a shock hazard.

Do *not* substitute parts or modify equipment. Because of the danger of introducing additional hazards, do *not* install unauthorized parts or modify the device. Return the device to National Instruments for service and repair to ensure that its safety features are not compromised.

You *must* insulate all of your signal connections to the highest voltage with which the device can come in contact.

Connections, including power signals to ground and vice versa, that exceed any of the maximum signal ratings on the device can create a shock or fire hazard, or can damage any or all of the boards connected to the chassis, the host computer, and the device. National Instruments is *not* liable for any damages or injuries resulting from incorrect signal connections.

Clean the module and accessories by brushing off light dust with a soft non-metallic brush. Remove other contaminants with a stiff non-metallic brush. The unit *must* be completely dry and free from contaminants before returning it to service.

2

Using Your NI 4472

This chapter explains how to install, configure, and test your NI 4472. It also provides information you need to know to acquire signals with your NI 4472.

Installing Your Software

Install your software before you install your NI 4472 device. Install your ADE, such as LabVIEW or Measurement Studio, according to the instructions on the CD and the release notes. After you have installed your ADE, install NI-DAQ according to the instructions on the CD and the *DAQ Quick Start Guide* included with your device.

Note It is important to install the NI-DAQ driver software before installing your NI 4472 to ensure that the device is properly detected.

Installing Your Hardware

The following are general installation instructions. Consult your PXI or CompactPCI chassis user manual or technical reference manual for specific instructions and warnings about installing new devices.

Note Follow the guidelines in your chassis documentation for installing plug-in hardware.

1. Turn off and unplug your PXI or CompactPCI chassis.
2. Choose an unused PXI or CompactPCI 5 V peripheral slot.

Note For maximum performance when using a non-PXI chassis, install the NI 4472 in a slot that supports bus arbitration or bus-master modules. The NI 4472 contains onboard bus-master DMA logic that can operate only in such a slot. If you choose a slot that does not support bus masters, you will have to disable the onboard DMA controller using your software. PXI-compliant chassis must have bus arbitration for all slots.

Caution The NI 4472 has connections to several reserved lines on the CompactPCI J2 connector. Use of these lines by other devices in your CompactPCI system can damage your equipment. Before installing an NI 4472 in a CompactPCI system that uses J2 connector lines for purposes other than PXI, see the *Using PXI with CompactPCI* section in Chapter 1, *Getting Started with Your NI 4472 for PXI/CompactPCI*.

3. Remove the filler panel for the peripheral slot you have chosen.
4. Ground yourself via a grounding strap or by holding a grounded object. Follow the ESD protection precautions described in the *Unpacking* section of Chapter 1, *Getting Started with Your NI 4472 for PXI/CompactPCI*.
5. Insert the NI 4472 in the selected 5 V slot. Use the injector/ejector handle to fully inject the device into place.
6. Attach the front panel of the NI 4472 to the front panel mounting rails of the PXI or CompactPCI chassis using the two screws on the device.
7. Visually verify the installation. Make sure the module is not touching other modules or components and is fully inserted in the slot.
8. Plug in and turn on the PXI or CompactPCI chassis.

The NI 4472 is now installed. You are now ready to configure your device.

Configuring Your Device

The NI 4472 is completely software configurable. The system software automatically allocates all device resources, including base memory address and interrupt level. These devices do not require DMA controller resources from your computer.

To check the configuration of your NI 4472, and to test its resource allocations to be sure they do not conflict with any others, follow these instructions:

1. Double-click the **Measurement & Automation** icon on your desktop to start Measurement & Automation Explorer (MAX).
2. In MAX, double-click **Devices and Interfaces** to open the folder, then double-click the icon for the NI 4472 for PXI/CompactPCI device you want to test.

Tip If your device does not appear in the Devices and Interfaces folder, select **View»Refresh** to refresh the MAX configuration tree.

3. Right-click the **PXI-4472 (Device *n*)** folder and select **Properties** from the pop-up menu to open the Configuring Device dialog box.
4. Click **Test Resources** to test the resource assignments. This test verifies that the PCI system has allocated resources correctly and that your NI 4472 can communicate with your controller. If there are no resource conflicts, a dialog box with the message **`The device has passed the test`** appears. Click **OK** to continue. If your device does not pass the test, refer to Appendix B, *Technical Support Resources*.

You can modify data acquisition-related settings, such as analog input polarity and range, analog input mode, and others, through National Instruments application-level software, such as LabVIEW or Measurement Studio, or with driver software such as NI-DAQ. Refer to device configuration instructions in your NI-DAQ documents and online help for more information.

Connecting Signals

The front panel of the NI 4472 is shown in Figure 2-1. The NI 4472 has eight male SMB connectors on its front panel for connecting analog signals, and one male SMB connector for connecting a digital trigger. The analog inputs are unbalanced differential channels with individually configurable AC/DC coupling and ICP-type current conditioning. The digital input can accept TTL/CMOS-compatible signals.

Note To minimize noise and ensure more accurate measurements, do not allow the connector shells of your SMB cables, SMB-to-BNC adapters, or BNC cables to touch each other or the PXI/CompactPCI chassis.

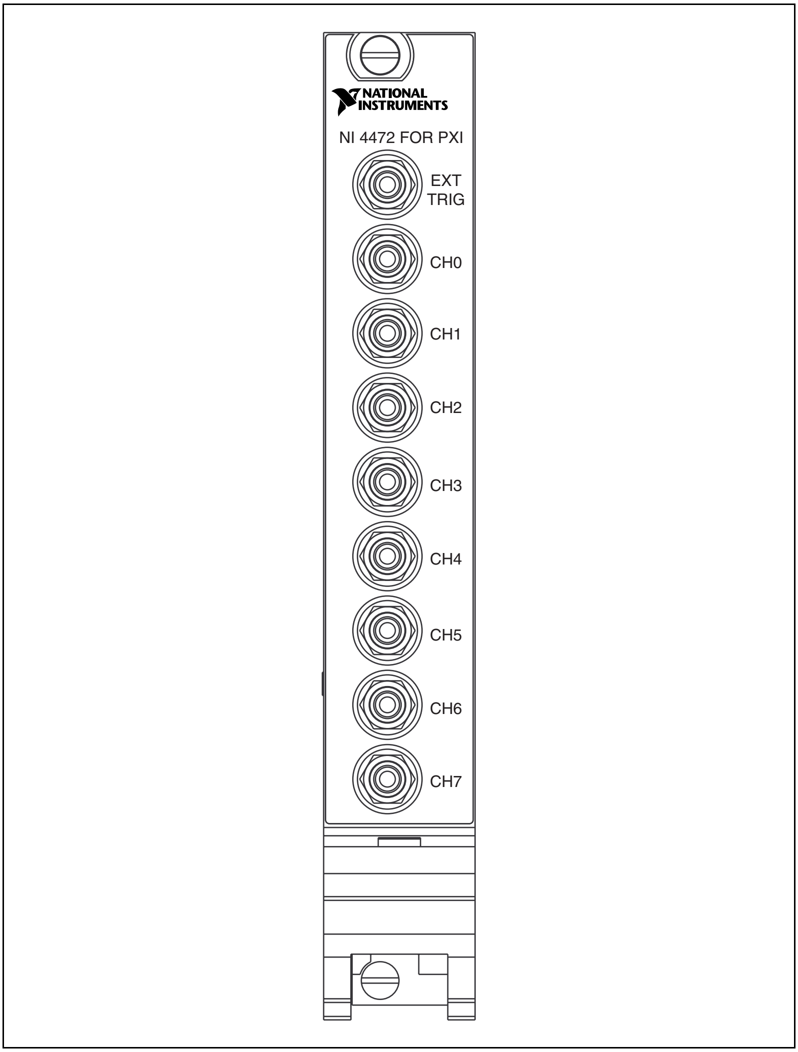

Figure 2-1. NI 4472 for PXI/CompactPCI Front Panel

Before configuring the analog input channels and making signal connections, you need to determine:

- Whether the input signal source is floating or grounded
- Whether the accelerometer or microphone you are using requires ICP-type current stimulation
- Whether AC or DC coupling is best for your application
- The voltage range of the input signal

Signal Sources

The analog input channels of the NI 4472 have unbalanced differential inputs. Figure 2-2 shows the input configurations for floating and grounded signal sources.

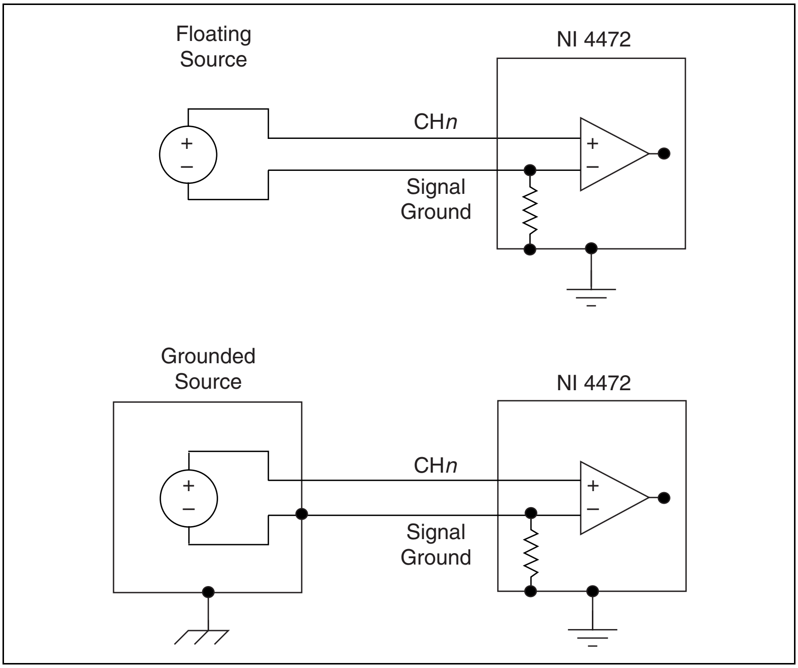

Figure 2-2. Input Configurations for the NI 4472

Caution Connecting a signal that varies more than ±2.5 V from the ground reference of the NI 4472 to the ground (shield) of any analog input channel can result in inaccurate measurements or even damage your device. National Instruments is *not* responsible for damage caused by such connections.

Floating Signal Sources

A floating signal source does not connect in any way to the building ground system, but has an isolated ground-reference point instead. Some examples of floating signal sources are outputs of transformers, thermocouples, battery-powered devices, optical isolator outputs, and isolation amplifiers. An instrument or device that has an isolated output is a floating signal source.

It is important to tie the ground reference of a floating signal to the analog input ground to establish a local reference for the signal. Otherwise, the measured input signal varies as the source floats out of the common-mode input range. With the NI 4472, you tie the signal ground to the analog input ground simply by attaching the signal cable to any of the analog input channel SMB connectors.

Note To ensure a good ground connection, securely fasten the front panel of the NI 4472 to the PXI chassis with both of the two screws attached for that purpose.

Grounded Signal Sources

A ground-referenced signal source connects in some way to the building system ground and is, therefore, already connected to a common ground point with respect to the NI 4472, assuming the PXI chassis is plugged into the same power system. Nonisolated outputs of instruments and devices that plug into the building power system fall into this category.

The difference in ground potential, or common-mode voltage, between two instruments connected to the same building power system is typically between 1 and 100 mV, but can be much higher if power distribution circuits are not properly connected. This difference in ground potential induces currents in the ground system that can cause errors in your measurement. For low common-mode voltages, the resistor on the signal ground is usually sufficient to reduce this current to negligible levels, but your results can vary depending on the system setup.

It is best to use the NI 4472 to acquire data from floating signal sources, but you can measure signals from grounded sources if the ground reference of the source does not vary by more than ±2.5 V from the ground reference of the NI 4472.

Current Conditioning

If you attach an ICP-type of accelerometer or microphone preamplifier to an analog input channel, you must enable the ICP circuitry for that channel in order to generate the required current. The ICP circuitry of any input channel can be enabled or disabled independently of that of any other input channel.

When ICP signal conditioning is enabled, large DC-offset voltages can occur on signal inputs due to the output bias voltage requirements of the ICP transducer you are using. To remove this offset you must enable

AC coupling on the affected input channels of the NI 4472. You should use DC coupling only if the impedance of the sensor does not exceed 2.5 kΩ and you are acquiring very low frequency signals.

Input Coupling

You can configure each analog input channel of the NI 4472 to be AC- or DC-coupled. If you select DC coupling, any DC offset present in the source signal is passed to the ADC. The DC-coupled configuration is usually best if the signal source has only small amounts of offset voltage (less than ±100 mV), or if the DC content of the acquired signal is important.

If the source has a significant amount of unwanted offset (bias voltage), you must set the switch for AC coupling to take full advantage of the input signal range. Using AC coupling results in a drop in the low-frequency response of the analog input. The −3 dB cutoff frequency is approximately 3.4 Hz, but the −0.01 dB cutoff frequency, for instance, is considerably higher at approximately 70.5 Hz.

Input Polarity and Input Range

The NI 4472 analog inputs are bipolar, that is, the input voltage range is centered on 0 V. The input voltage range is ±10 V with 1.19 µV resolution, and is always at a gain of 1.0 (0 dB). Due to the large dynamic range of its ADC, the NI 4472 does not require programmable gain for most applications. Since the NI 4472 does not have hardware to adjust the input gain, the component count in the input signal path is reduced, resulting in a cleaner signal. If the input signal has an amplitude greater than ±10 V, it will be clipped and introduce large errors that can be easily identified in the frequency spectrum.

Caution Connections that exceed the rated input voltages can damage the computer and the connected equipment. National Instruments is *not* liable for any damages resulting from such connections.

All data read from the ADC is interpreted as two's complement format. In two's complement mode, digital data values read from the analog input channel are either positive or negative.

Digital Trigger

You can use the EXT TRIG SMB connector on the NI 4472 for dedicated external digital triggering.

Using Test Panels to Acquire a Signal

To quickly test your signal connections and the operation of your system, you can use the Test Panels to view a signal input to your NI 4472. To do so, follow these instructions:

1. Connect a known signal to an analog input channel on the NI 4472.
2. Launch MAX.
3. Open the **Devices and Interfaces** folder.
4. Right-click the icon for the NI 4472 device you want to test and select **Test Panel** from the pop-up menu.
5. Set your parameters as follows:
   - Channel—Select the input channel you are using.
   - Sample Rate (Hz)—Enter a sampling rate that is at least twice the highest frequency component of your input signal.
   - Data Mode—Select **Continuous**.
   - Y Scale Mode—Select **Auto Scale**.
6. Click **Start** to begin a continuous signal acquisition.

The Test Panel window displays a graph of the signal you input.

Field Wiring Considerations

Environmental noise can affect the accuracy of measurements made with your NI 4472 if you do not take proper care when running signal wires between signal sources and the device. For more information, refer to National Instruments Application Note 025, *Field Wiring and Noise Considerations for Analog Signals*.

The following recommendations apply mainly to analog input signal routing to the device although they also apply to signal routing in general.

Minimize noise pickup and maximize measurement accuracy by taking the following precautions:

- Route signals to the device carefully. Keep cabling away from noise sources. The most common noise source in a PXI data acquisition system is the video monitor. Separate the monitor from the analog signals as much as possible.
- Separate NI 4472 signal lines from high-current or high-voltage lines. These lines can induce currents in or voltages on the NI 4472 signal

lines if they run in parallel paths at a close distance. To reduce the magnetic coupling between lines, separate them by a reasonable distance if they run in parallel, or run the lines at right angles to each other.

- Do *not* run signal lines through conduits that also contain power lines.
- Protect signal lines from magnetic fields caused by electric motors, welding equipment, breakers, or transformers by running them through special metal conduits.

Selecting Your Sample Clock Frequency

The eight analog input channels of the NI 4472 are simultaneously sampled at any software-programmable rate from 1.0 kS/s to 102.4 kS/s in 24.4 mS/s increments (worst case). The device uses direct digital synthesis (DDS) technology so that you can choose the correct sample rate for your application. All the input channels acquire data at the same rate. One input channel *cannot* acquire data at a different rate from another input channel.

Synchronizing Multiple Devices

The NI 4472 can send or receive the DDS clock signal and the synchronization start signal to or from other NI 4472 devices on the PXI bus to synchronize data acquisition. In a multi-device system, a master device drives the clock and synchronization signals to other slave, or receiving, devices.

To synchronize two or more NI 4472 devices, one of the devices must be in PXI Slot 2. This device is the master, and the NI 4472 devices in other slots are slaves. The master broadcasts the ADC clock to the other NI 4472 devices on the PXI Star trigger lines, and uses the PXI Trigger 5 (RTSI 5) line to synchronize the start of the acquisition. For specific LabVIEW programming instructions, refer to *How to Synchronize Multiple PXI-DSA Boards* in *LabVIEW Help*; for using NI-DAQ with other ADEs, refer to *Synchronizing Multiple PXI-DSA Boards: Select_Signal* in *NI-DAQ Help*.

Caution Do *not* use RTSI 5 to drive any signals in your PXI system if you are synchronizing multiple NI 4472 devices. The synchronization signal is driven on RTSI 5, so driving other signals on RTSI 5 could lead to double-driving the line, which can result in unpredictable behavior and might damage your system.

Device Configuration Issues

Selecting a sample rate that is less than two times the frequency of a band of interest can lead you to believe the device is functioning improperly. By undersampling the signal, you might receive what appears to be a DC signal. This situation is due to the sharp antialiasing filters that remove frequency components above the sampling frequency. If you have a situation where this occurs, simply increase the sample rate until it meets the requirements of the *Nyquist Sampling Theorem*. For more information on the filters and aliasing, refer to the *Antialias Filtering* section of Chapter 3, *Device Overview and Theory of Operation*.

Unlike other converter technologies, delta-sigma converters must be run continuously and at a minimum clock rate. To operate within guaranteed specifications, the A/D converters must operate at a minimum sample rate of 1.0 kS/s. This minimum rate is required to keep the internal circuitry of the converters running within specifications. You are responsible for selecting sample rates that fall within the specified limits. Failure to do so can greatly affect the specifications.

3

Device Overview and Theory of Operation

This chapter presents an overview of the hardware functions of your NI 4472, and other useful information for understanding how the device works.

Functional Overview

Figure 3-1 shows a block diagram of the digital functions, and the analog function block diagram is shown in Figure 3-2.

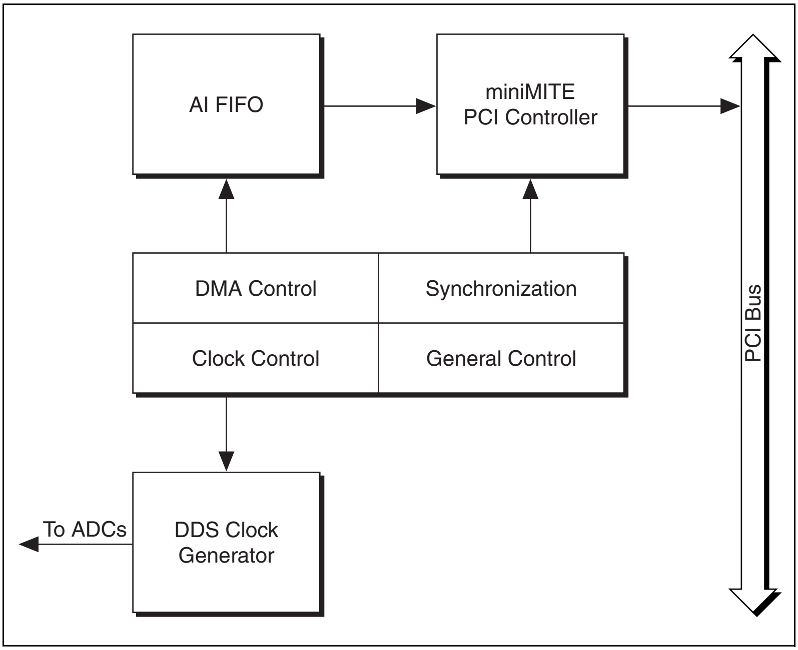

Figure 3-1. Digital Function Block Diagram

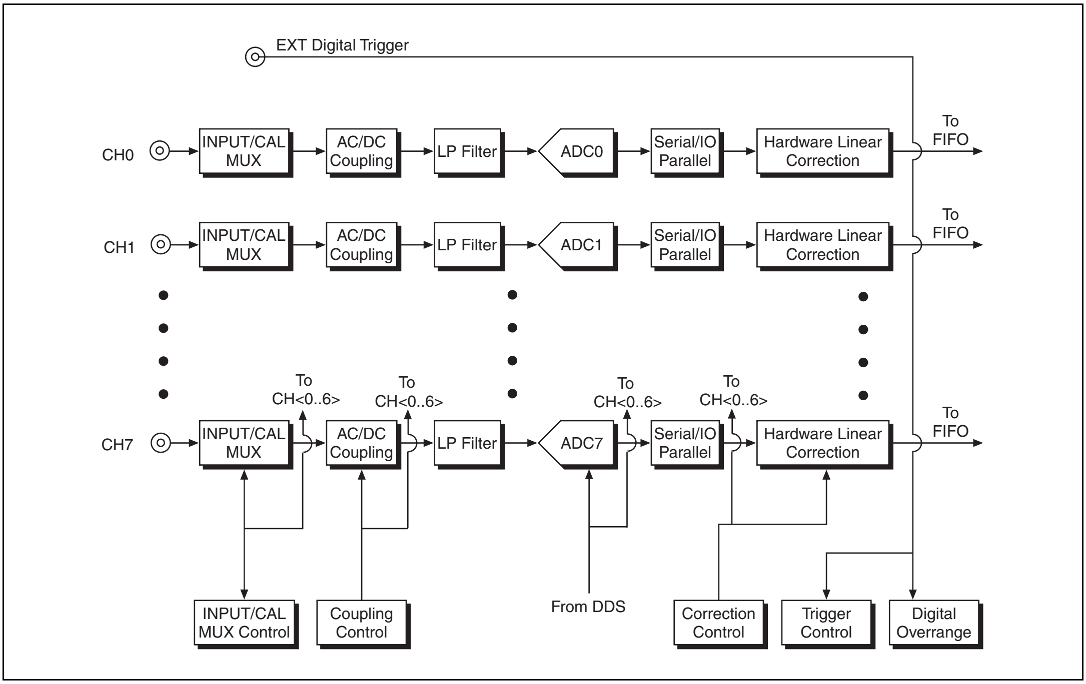

Figure 3-2. Analog Function Block Diagram

I/O Connectors

Caution Connections that exceed any of the maximum ratings for input signals on the NI 4472 can damage the device, the computer, and the associated accessories. National Instruments is *not* liable for any damage resulting from such signal connections.

The front panel of the NI 4472 has nine SMB male connectors for attaching signal inputs.

The EXT TRIG connector is the input for the PFI0/EXT_TRIG signal. Triggers cannot be output from the EXT TRIG connector. The EXT TRIG line is compatible with TTL voltage levels.

CH<0..7> are analog input channels 0 through 7. Input impedance on the positive (signal) wire of each input channel is 1 MΩ in parallel with 60 pF to ground. Input impedance on the negative (shield) wire is 50 Ω in parallel with 0.02 µF to ground. The signal line of each analog input channel circuit is protected to ±42.4 V, whether power is on or off. The shield side of the analog input channels is rated for ±2.5 V.

Analog Input Signal Connections

Figure 3-3 shows a diagram of one of the eight identical NI 4472 analog input stages.

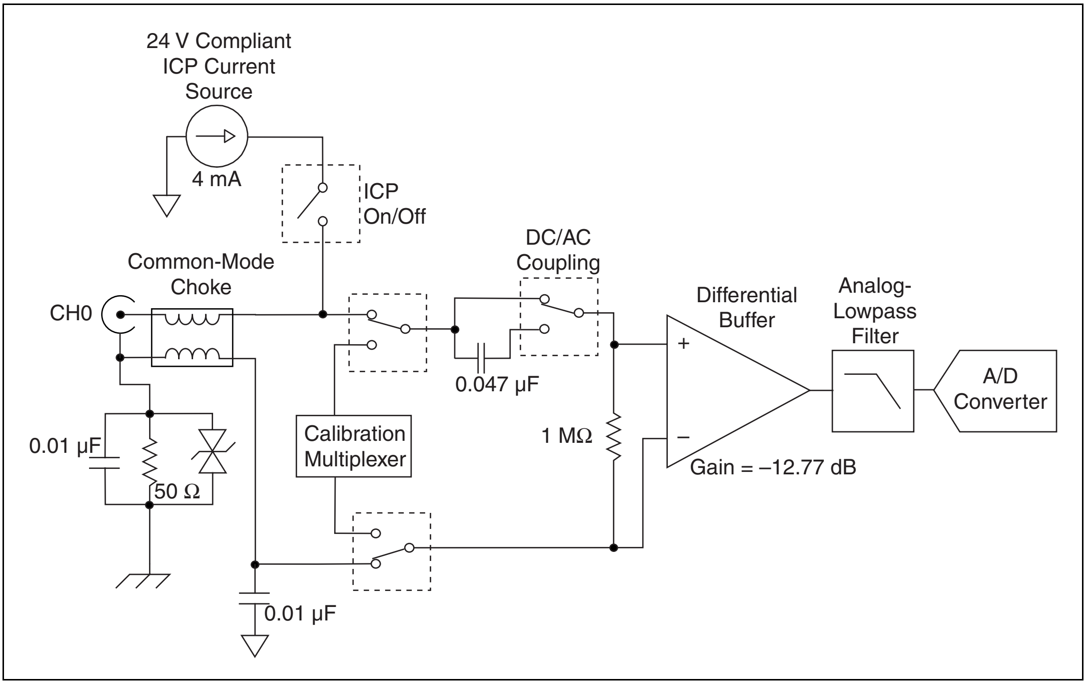

Figure 3-3. Analog Input Stage

The analog input stage presents high input impedance to the analog input signals connected to your NI 4472. Signals are routed to the positive inputs of the analog input stage, and their returns are routed to AIGND through a common-mode choke. Your NI 4472 ADCs measure these signals when they perform A/D conversions.

These input channels have 24-bit resolution and are simultaneously sampled at software-programmable rates from 1.0 to 102.4 kS/s in 24.4 mS/s increments. This flexibility in sample rates makes the device well-suited for a wide variety of applications, including audio and vibration analysis.

The unbalanced differential analog inputs have software-selectable AC/DC coupling.

Calibration

The NI 4472 analog inputs have calibration adjustments. Onboard calibration circuits remove the offset and gain errors for each channel. For complete calibration instructions, refer to Chapter 4, *Calibration*.

Antialias Filtering

A sampling system (such as an ADC) can represent signals of only limited bandwidth. Specifically, a sampling rate of f_s can only represent signals with a maximum frequency of $f_s/2$. This maximum frequency is known as the *Nyquist frequency*. The bandwidth from 0 Hz to the Nyquist frequency is the *Nyquist bandwidth*. If a signal is input to the sampling system with frequency components that exceed the Nyquist frequency, the sampler cannot distinguish these parts of the signal from some signals with frequency components less than the Nyquist frequency.

For example, suppose a sampler (such as an ADC) is sampling at 1,000 S/s. If a 400 Hz sine wave is input, then the resulting samples accurately represent a 400 Hz sine wave. However, if a 600 Hz sine wave is input, the resulting samples again appear to represent a 400 Hz sine wave because this signal exceeds the Nyquist frequency (500 Hz) by 100 Hz. In fact, any sine wave with a frequency greater than 500 Hz that is input is represented incorrectly as a signal between 0 and 500 Hz. The apparent frequency of this sine wave is the absolute value of the difference between the frequency of the input signal and the closest integer multiple of 1,000 Hz (the sampling rate). Therefore, if a 2,325 Hz sine wave is input, its apparent frequency is as follows:

$$2{,}325 - (2)(1{,}000) = 325 \text{ Hz}$$

If a 3,975 Hz sine wave is input, its apparent frequency is as follows:

$$(4)(1{,}000) - 3{,}975 = 25 \text{ Hz}$$

The process by which the sampler modulates these higher frequency signals back into the 0 to 500 Hz baseband is called *aliasing*.

If the signal in the previous example is not a pure sine wave, the signal can have many components (harmonics) that lie above the Nyquist frequency. If present, these harmonics are erroneously aliased back into the baseband and added to the parts of the signal that are sampled accurately, producing a distorted sampled data set. To avoid this, it is important to input to the sampler only those signals that can be accurately represented—those whose frequency components all lie below the Nyquist frequency. To make sure that only those signals go into the sampler, a lowpass filter is applied to signals before they reach the sampler.

The NI 4472 includes a two pole anti-alias lowpass filter for each input channel. This filter has a cutoff frequency of about 400 kHz. Because its cutoff frequency is significantly higher than the data sample rate, the analog filter has an extremely flat frequency response in the bandwidth of interest, and it has very little phase error.

The analog filter precedes the analog sampler. In the NI 4472, the analog sampler operates at 64 times the selected sample rate for rates above 51.2 kS/s, and at 128 times the selected sample rate for rates below 51.2 kS/s. For example, if you select a sample rate of 102.4 kS/s, the ADC operates at 6.5536 MS/s (64 × 102.4 kS/s).

The analog sampler is a 1-bit ADC. The 1-bit oversampled data that the analog sampler produces is passed on to a digital antialiasing filter that is built into the ADC chip. This filter also has extremely flat frequency response and no phase error, but its roll-off near the cutoff frequency (about 0.4863 times the sample rate) is extremely sharp, and the rejection above 0.5465 times the sample rate is greater than 110 dB. The output stage of the digital filter resamples the higher frequency data stream at the output data rate, producing 24-bit digital samples.

The digital filter in each channel passes only those signal components with frequencies that lie below the Nyquist frequency or within one Nyquist bandwidth of multiples of 64 times the sample rate (for sample rates above 51.2 kS/s) or 128 times the sample rate (for sample rates below 51.2 kS/s). The analog filter in each channel rejects possible aliases (mostly noise) from signals that lie near these multiples. Figures 3-4 and 3-5 show the frequency response of the NI 4472 input circuitry.

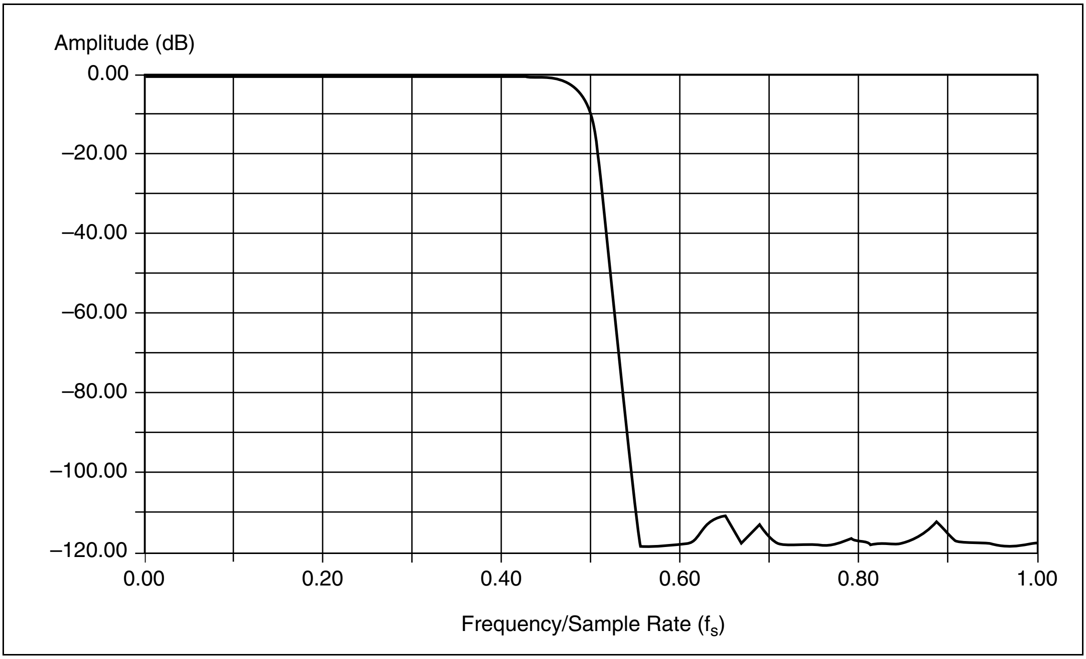

Figure 3-4. Input Frequency Response

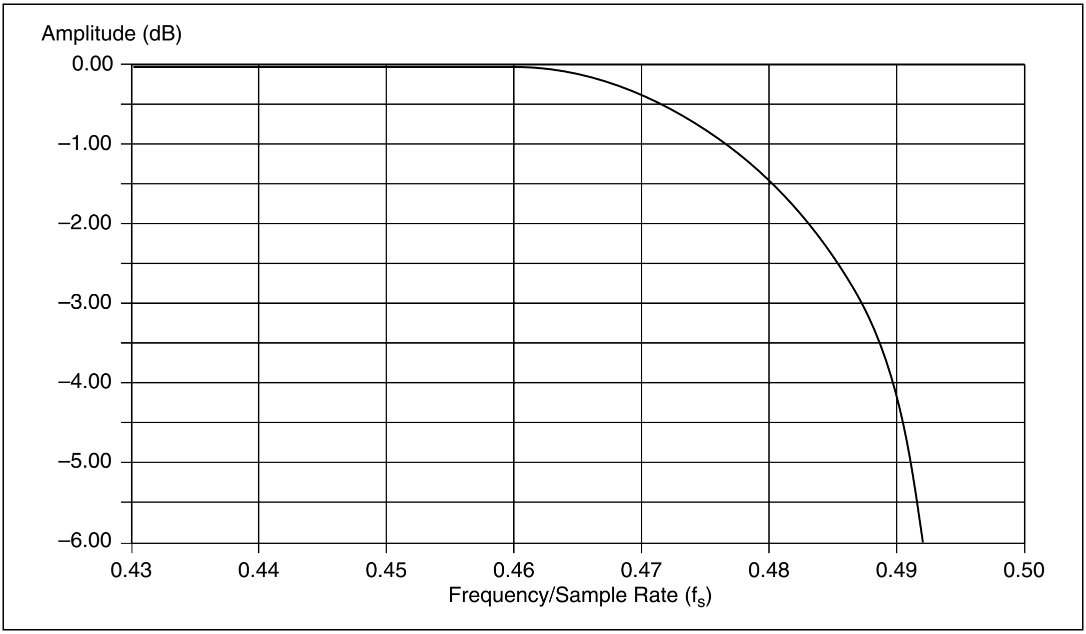

Figure 3-5. Input Frequency Response Near the Cutoff

Because the ADC samples at 64 or 128 times the data rate, frequency components above one-half of the oversampling rate—32 or 64 times the data rate—can alias. The digital filter rejects most of the frequency range over which aliasing can occur. However, the filter can do nothing about components that lie close to integer multiples of the oversampling rate—64 (for $f_s > 51.2$ kS/s), 128, and 256 times the data rate, and so on—because it cannot distinguish these components from components in the baseband (0 Hz to the Nyquist frequency). If, for instance, the sample rate is 50 kS/s and a signal component lies within 25 kHz of 6.4 MHz (128×50 kHz), this signal is aliased into the passband region of the digital filter and is not attenuated. The purpose of the analog filter is to remove these higher frequency components near multiples of the oversampling rate before they get to the sampler and the digital filter.

While the frequency response of the digital filter scales in proportion to the sample rate, the frequency response of the analog filter remains fixed. The response of the filter is optimized to produce good high-frequency alias rejection while having a flat in-band frequency response. Because this filter is second-order, its roll-off is rather slow. The filter has good alias rejection at high sample rates, but as a result of its slow roll-off, does not filter aliases as well at lower sample rates. The alias rejection near 64 or 128 times the sample rate versus sample rate for the NI 4472 is illustrated in Figure 3-6. For frequencies not near multiples of the oversample rate, the rejection is better than 110 dB.

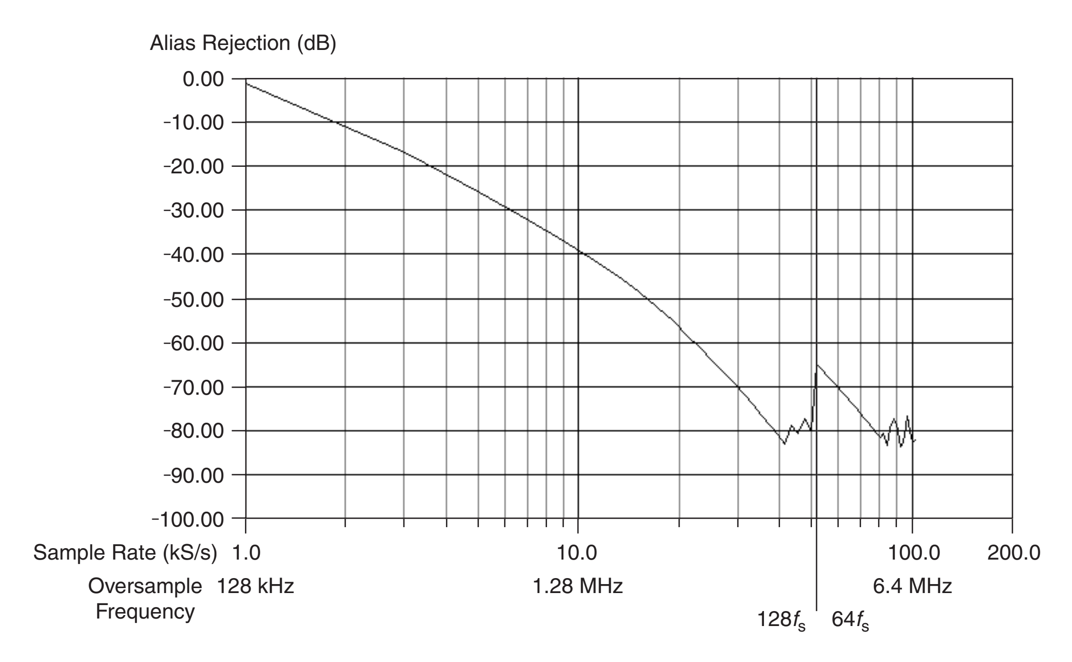

Figure 3-6. Alias Rejection at the Oversample Rate

No filter can prevent a type of aliasing caused by a *clipped* or *overranged* waveform, that is, one that exceeds the voltage range of the ADC. When clipping occurs, the ADC assumes the closest value in its digital range to the actual value of the signal, which is always either +8,388,607 ($2^{23} - 1$) or –8,388,608 (-2^{23}). Clipping always results in an abrupt change in the slope of the signal and causes the corrupted digital data to have high-frequency energy. This energy is spread throughout the frequency spectrum, and because the clipping happens *after* the antialiasing filters, the energy is aliased back into the baseband. The remedy for this problem is simple: do not allow the signal to exceed the nominal input range. Figure 3-7 shows the spectra of 10.5 V_{rms} and 10.0 V_{rms}, 3.0 kHz sine waves. The signal-to-THD-plus-noise (THD+N) ratio is 35 dB for the clipped waveform and 92 dB for the properly ranged waveform. Aliases of all the harmonics due to clipping appear in Figure 3-7a.

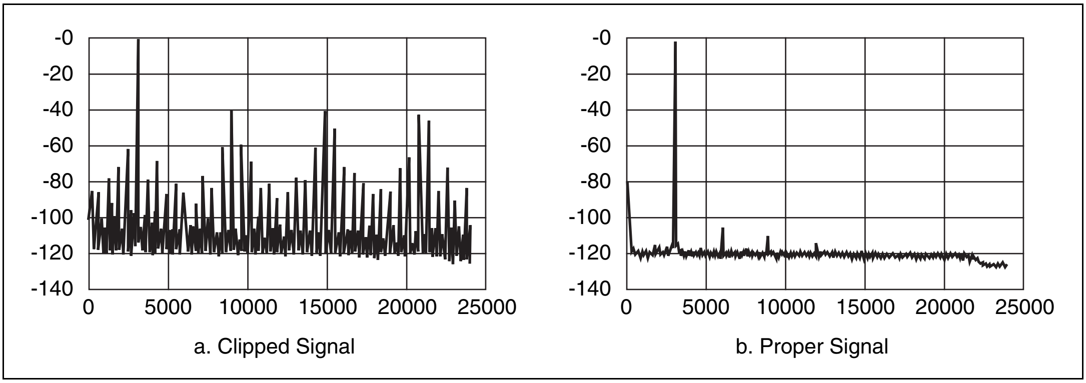

Figure 3-7. Comparison of a Clipped Signal to a Proper Signal

An overrange can occur on the analog signal as well as on the digitized signal. Furthermore, an analog overrange can occur independently from a digital overrange and vice versa. For example, a piezoelectric accelerometer might have a resonant frequency that, when stimulated, can produce an overrange in the analog signal, but because the delta-sigma technology of the ADC uses very sharp antialiasing filters, the overrange is not passed into the digitized signal. Conversely, a sharp transient on the analog input might not overrange, but due to the step response of those same delta-sigma antialiasing filters, the digitized data might be clipped.

The ADC

The NI 4472 ADC uses a method of A/D conversion known as delta-sigma modulation. If the data rate is 51.2 kS/s, each ADC actually samples its input signal at 6.5536 MS/s (128 times the data rate) and produces 1-bit samples that are applied to the digital filter. This filter then expands the data to 24 bits, rejects signal components greater than 25.6 kHz (the Nyquist frequency), and re-samples the data at the more conventional rate of 51.2 kS/s.

Although a 1-bit quantizer introduces a large amount of quantization error to the signal, the 1-bit, 6.5536 MS/s from the ADC carry all the information used to produce 24-bit samples at 51.2 kS/s. The delta-sigma ADC achieves this conversion from high speed to high resolution by adding a large amount of random noise to the signal so that the resulting quantization noise, although large, is restricted to frequencies above 25.6 kHz. This noise is not correlated with the input signal and is almost completely rejected by the digital filter.

The resulting output of the filter is a band-limited signal with a dynamic range of over 100 dB. One of the advantages of a delta-sigma ADC is that it uses a 1-bit DAC as an internal reference. As a result, the delta-sigma ADC is free from the kind of differential nonlinearity (DNL) that is inherent in most high-resolution ADCs. This lack of DNL is especially beneficial when the ADC is converting low-level signals, in which noise and distortion are directly affected by converter DNL.

Noise

The NI 4472 analog inputs typically have a dynamic range of more than 100 dB. The dynamic range of a circuit is the ratio of the magnitudes of the largest signal the circuit can carry to the residual noise in the absence of a signal. In a 24-bit system, the largest signal is taken to be a full-scale sine wave that peaks at the codes +8,388,607 and −8,388,608. Such a sine wave has an RMS magnitude of 8,388,608/1.414 = 5,932,537.482 least significant bits (LSBs).

Several factors can degrade the noise performance of the inputs. One of these factors is noise picked up from nearby electronic devices. The NI 4472 works best when it is kept as far away as possible from other plug-in devices, power supplies, disk drives, and computer monitors. Cabling is also critical. Make sure to use well-shielded coaxial or balanced cables for all connections, and route the cables away from sources of interference such as computer monitors, switching power supplies, and fluorescent lights. Refer to the *Field Wiring Considerations* section of Chapter 2, *Using Your NI 4472*, for more information.

One way to reduce the effects of noise on your measurements is to choose the sample rate carefully. Take advantage of the anti-alias filtering that removes signals beyond the band of interest. Computer monitor noise, for example, typically occurs at frequencies between 15 and 50 kHz. If the signal of interest is restricted to below 10 kHz, for example, the anti-alias filters reject the monitor noise outside the frequency band of interest. The frequency response inside the band of interest is not influenced if the sample rate is between roughly 21.6 and 28 kS/s.

Trigger

In addition to supporting internal software triggering and external digital triggering to initiate a data acquisition sequence, the NI 4472 also supports analog level triggering. You can configure the trigger circuit to monitor any one of the analog input channels to generate the level trigger. Choosing an input channel as the level trigger channel does not influence the input channel capabilities. The level trigger circuit compares the full 24 bits of the programmed trigger level with the digitized 24-bit sample.

The trigger circuit generates an internal digital trigger based on the input signal and the user-defined trigger levels. Any of the timing sections of the DAQ-STC can use this level trigger, including the analog input, RTSI, and general-purpose counter/timer sections. For example, you can configure the analog input section to acquire a given number of samples after the analog input signal crosses a specific threshold.

Due to the nature of delta-sigma converters, the triggering circuits operate on the digital output of the converter. Since the trigger is generated at the output of the converter, triggers can occur only when a sample is actually generated. Placing the triggering circuits on the digital side of the converter does not affect most measurements unless an analog output is generated based on the input trigger. In this case, you account for the inherent delays of the finite impulse response (FIR) filters internal to the delta-sigma converters. The delay through the input converter is 38.8 sample periods.

During repetitive sampling of a waveform, you might observe jitter due to the uncertainty of where a trigger level falls compared to the actual digitized data. Although this trigger jitter is never greater than one sample period, it can seem quite bad when the sample rate is only twice the bandwidth of interest. This jitter has no effect on the processing of the data, and you can decrease this jitter by oversampling.

Five analog level triggering modes are available, as shown in Figures 3-8 through 3-12. You can set **lowValue** and **highValue** independently in the software.

In below-low-level triggering mode, shown in Figure 3-8, the trigger is generated when the signal value is less than **lowValue**. **highValue** is unused.

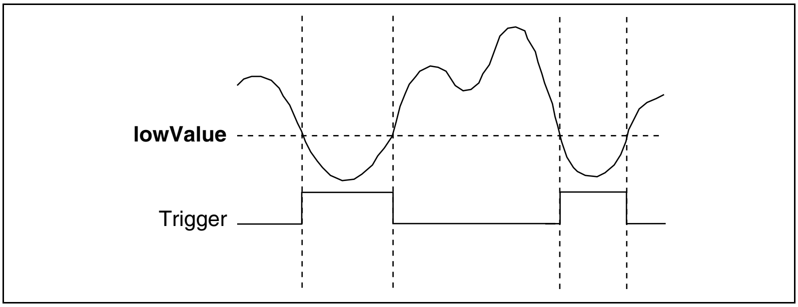

Figure 3-8. Below-Low-Level Triggering Mode

In above-high-level triggering mode, shown in Figure 3-9, the trigger is generated when the signal value is greater than **highValue**. **lowValue** is unused.

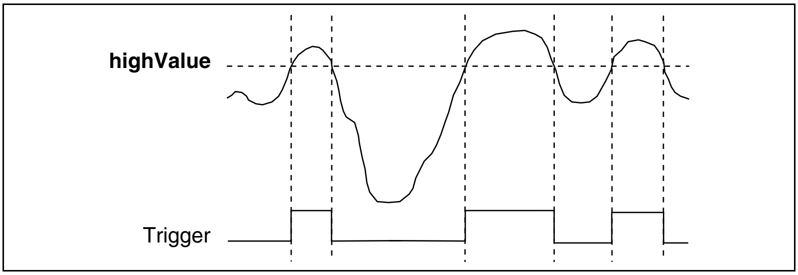

Figure 3-9. Above-High-Level Triggering Mode

In inside-region triggering mode, shown in Figure 3-10, the trigger is generated when the signal value is between **lowValue** and **highValue**.

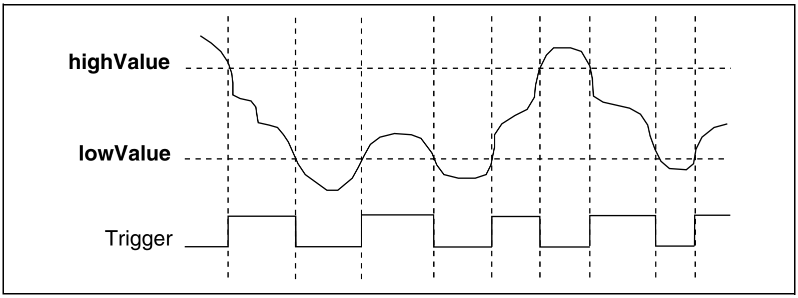

Figure 3-10. Inside-Region Triggering Mode

In high-hysteresis triggering mode, shown in Figure 3-11, the trigger is generated when the signal value is greater than **highValue**, with the hysteresis specified by **lowValue**.

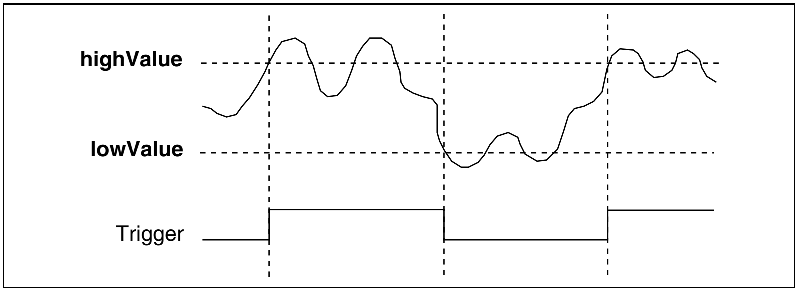

Figure 3-11. High-Hysteresis Triggering Mode

In low-hysteresis triggering mode, shown in Figure 3-12, the trigger is generated when the signal value is less than **lowValue**, with the hysteresis specified by **highValue**.

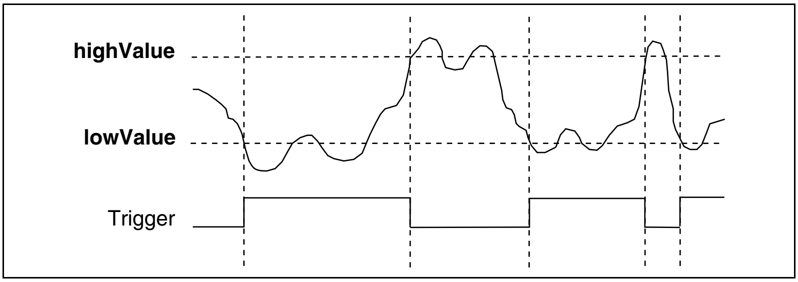

Figure 3-12. Low-Hysteresis Triggering Mode

You can use the EXT TRIG input SMB connector on the NI 4472 for dedicated external digital triggering.

Using digital triggering, you can trigger the NI 4472 from any other National Instruments device that has the RTSI-bus feature and resides on the same PXI bus. You can programmatically route any PXI trigger to the NI 4472 except TRIG5, which is reserved for internal use.

Device and PXI Clocks

An NI 4472 can use either its internal DDS timebase or a timebase received over the PXI bus. In addition, if you configure the device to use the internal timebase, you can program the device to drive its internal timebase over the PXI bus to another device that you program to receive this timebase signal. The default configuration at startup is to use the internal timebase without driving the PXI bus timebase signal. This timebase is software-selectable.

4

Calibration

This chapter discusses the calibration procedures for your NI 4472. Your NI 4472 comes with a calibration certificate. The certificate contains a unique tracking number linking your device to the National Instruments corporate databases where the traceability information is stored.

Calibration refers to the process of minimizing measurement and output voltage errors by making small circuit adjustments. On the NI 4472 devices, these adjustments are made to the digital data coming from the ADCs. If you are using the NI-DAQ device driver, the software includes calibration functions for performing all of the steps in the calibration process. Some form of device calibration is required for all but the most forgiving applications. If you do not calibrate your device, your signals and measurements could have very large offset and gain errors. The four levels of calibration available are described in this chapter. The first level is the fastest, easiest, and least accurate, whereas the last level is the slowest, most difficult, and most accurate.

Loading Calibration Constants

Your NI 4472 device is factory calibrated at approximately 25 °C to the levels indicated in Appendix A, *Specifications*. Before shipment, the associated calibration constants—the values that were written to the calibration circuitry to achieve calibration in the factory—are stored in the onboard nonvolatile memory (EEPROM). Because the calibration circuits have no memory, they do not retain calibration information when the device is unpowered. Loading calibration constants refers to the process of loading the calibration circuits with the values stored in the EEPROM. NI-DAQ determines when this is necessary and does it automatically.

Self-Calibration

Your NI 4472 can measure and correct almost all of its calibration-related errors without any external signal connections. Your National Instruments software provides a self-calibration method. This self-calibration process, which generally takes less than a minute, is the preferred method of assuring accuracy in your application. Initiate self-calibration to minimize the effects of any offset and gain drifts, particularly those due to temperature variations.

Your NI 4472 has an onboard calibration reference to ensure the accuracy of self-calibration. Its specifications are listed in Appendix A, *Specifications*. The reference voltage is measured at the factory or during an external calibration operation and stored in the EEPROM for subsequent self-calibrations.

Immediately after self-calibration, the only significant residual calibration error could be gain error due to time or temperature drift of the onboard voltage reference. This error is addressed by external calibration, which is discussed in the *External Calibration* section. If you are interested primarily in relative measurements, you can ignore a small amount of gain error, and self-calibration should be sufficient.

External Calibration

The onboard calibration reference voltage is stable enough for most applications, but if you are using your device at an extreme temperature or if the onboard reference has not been measured for two years or more, you might want to externally calibrate your device.

External calibration refers to calibrating your device with a known external reference rather than relying on the onboard reference. The new calibration constants are stored in the onboard EEPROM, overwriting the factory calibration constants.

Externally calibrate your device by calling the NI-DAQ calibration function. When you perform an external calibration, be sure to use a very accurate external DC reference. The reference should be several times more accurate than the device itself. For example, to calibrate the NI 4472, the external reference should have a DC accuracy better than ±115 ppm (±0.001 dB).

Note When you calibrate your NI 4472, make sure that ICP power is turned off to avoid affecting the reference voltage reading.

Traceable Recalibration

Traceable recalibration is divided into three different areas—factory, on-site, and third party. Devices typically require this type of recalibration every year.

If you require factory recalibration, send your NI 4472 back to National Instruments. National Instruments will send the device back to you with a new calibration certificate. Please check with National Instruments for additional information such as cost and delivery times.

If your company has a metrology laboratory, you can recalibrate the NI 4472 at your location (on-site). You can also send your NI 4472 to a third party for recalibration. Please contact National Instruments for approved third-party calibration service providers.

Calibration documentation and function libraries are available online at `ni.com`

A

Specifications

This appendix lists the specifications of the NI 4472. These specifications are typical at 25 °C unless otherwise noted. The system must be allowed to warm up for 15 minutes to achieve the rated accuracy.

Note Be sure to keep the filler panels on all unused slots in your PXI/CompactPCI chassis to maintain forced air cooling.

Analog Input

Channel Characteristics

Number of channels .... 8, simultaneously sampled

Input configuration................................ Unbalanced differential, 50 Ω to ground on shield

Resolution .... 24 bits, nominal

Type of ADC... Delta-sigma

Oversampling, for sample rate (f_s):

1.0 kS/s $\leq f_s \leq 51.2$ kS/s .... 128 f_s

51.2 kS/s $< f_s \leq 102.4$ kS/s .... 64 f_s

Sample rates (f_s) .... 1.0 kS/s to 102.4 kS/s in 24.4 mS/s increments

Frequency accuracy................................ ±25 ppm

Input signal range.................................. 10 V_{peak}

FIFO buffer size .... 1,024 samples

Data transfers .... DMA, programmed I/O, interrupt

Transfer Characteristics

Offset (residual DC) ....±3 mV, max

Gain (amplitude accuracy).....................±0.1 dB, max, f_{in} = 1 kHz

Amplifier Characteristics

Input impedance (ground referenced)

Positive input..................................1 MΩ in parallel with 60 pF

Negative input (shield) ....50 Ω in parallel with 0.02 µF

Flatness (relative to 1 kHz)....................±0.03 dB, DC to 0.4535 f_s, max, DC-coupled

–3 dB bandwidth...................................0.4863 f_s

Input coupling..AC or DC, software-selectable

AC –3 dB cutoff frequency ....3.4 Hz

Overvoltage protection

Positive input..................................±42.4 V

Negative input (shield) ....±2.5 V

Inputs protected ....ACH<0..7>

Common mode rejection ratio (CMRR)

f_{in} <1 kHz ....> 60 dB, min

Noise .... Refer to Figures A-1 through A-3

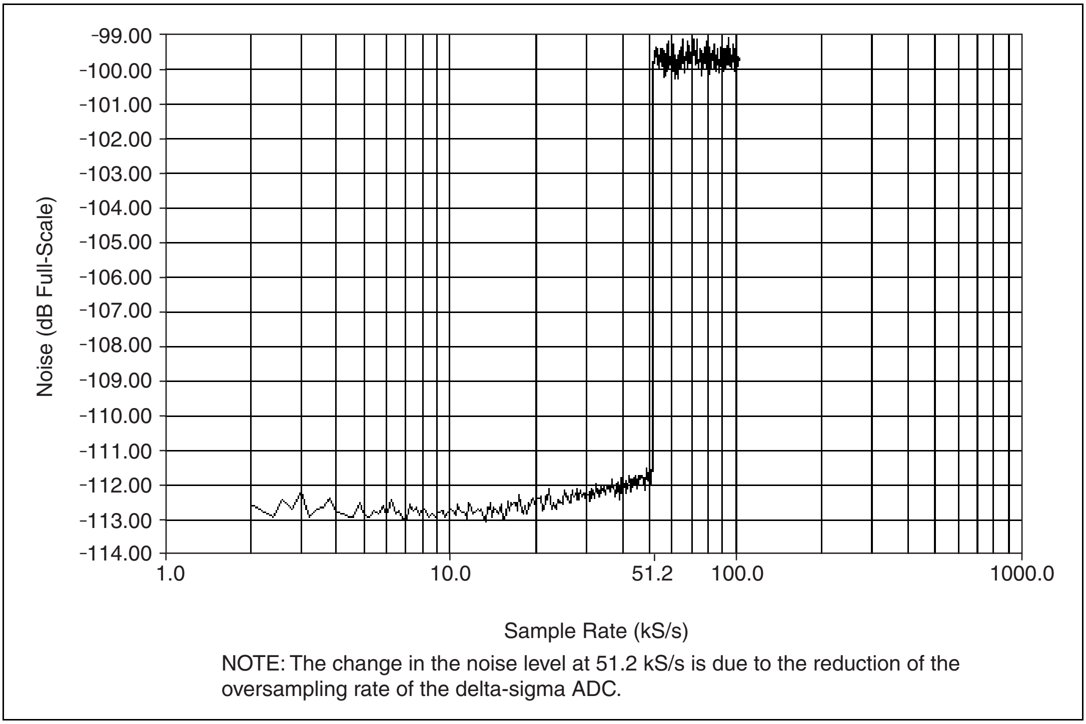

Figure A-1. Idle Channel Noise

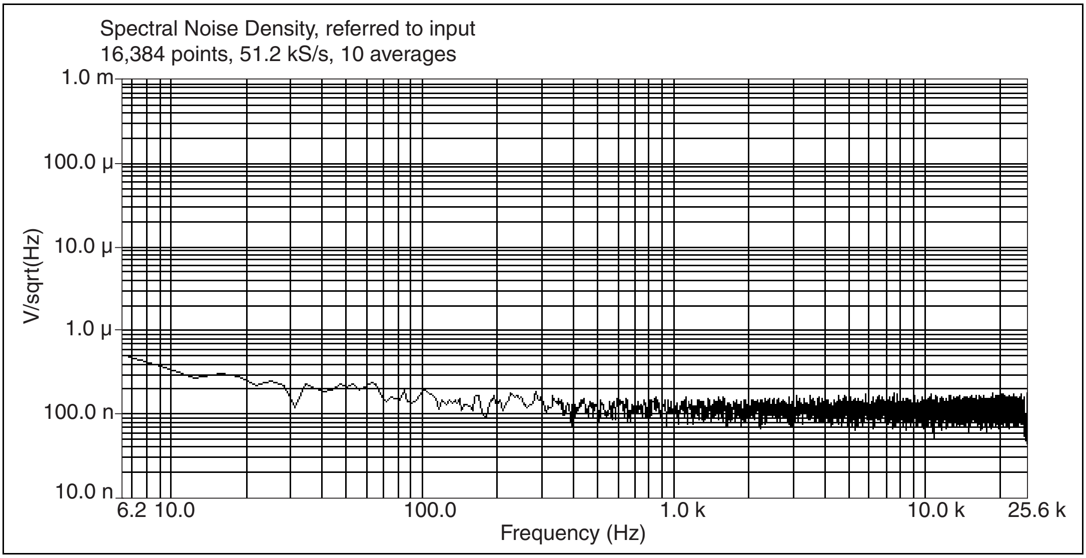

Figure A-2. Input Noise Spectral Density at 128-Times Oversampling

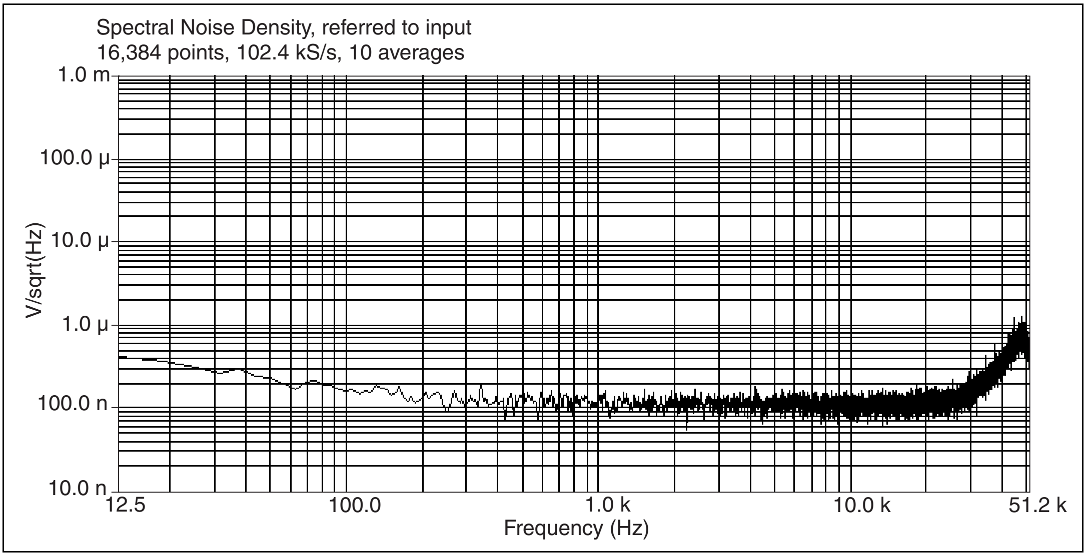

Figure A-3. Input Noise Spectral Density at 64-Times Oversampling

Dynamic Characteristics

Alias-free bandwidth (passband) ....DC (0 Hz) to 0.4535 f_s

Stop band ....0.5465 f_s

Alias rejection .... 110 dB

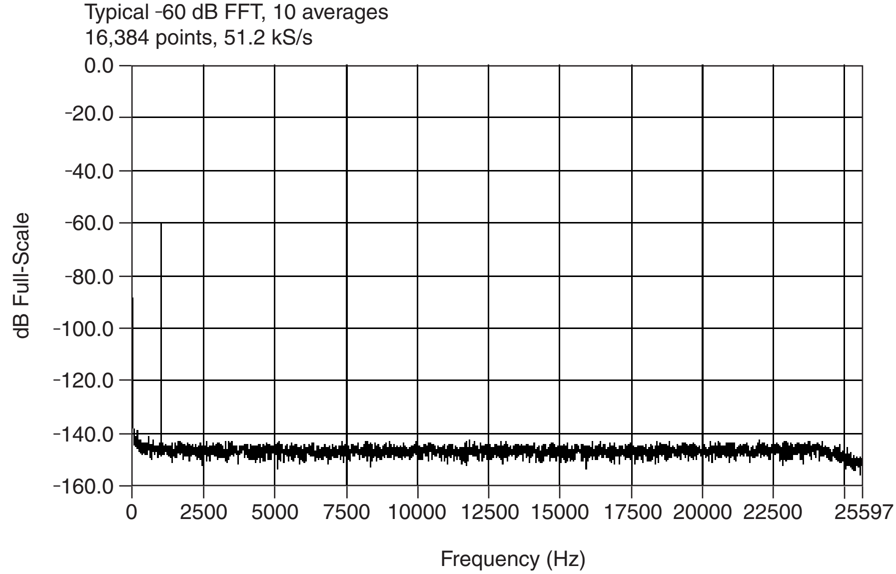

Figure A-4. Spurious-Free Dynamic Range at 51.2 kS/s

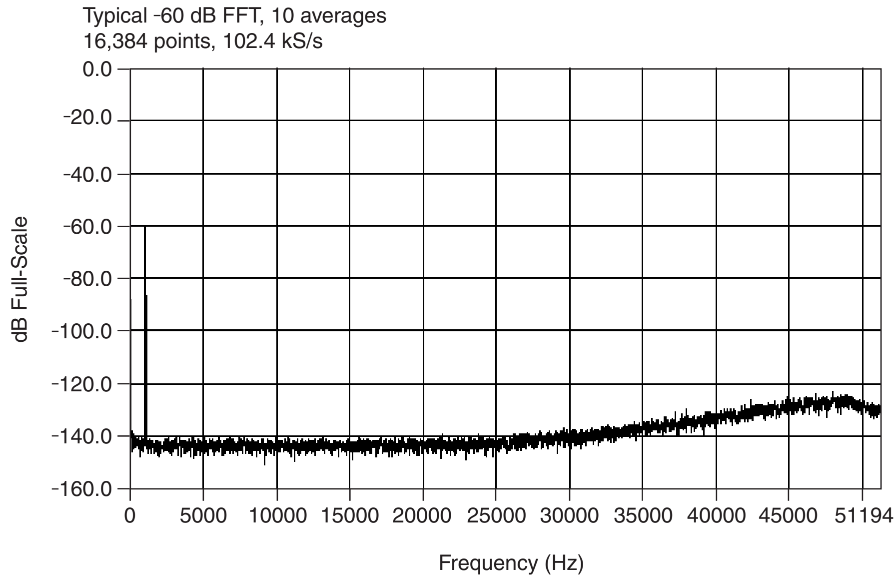

Figure A-5. Spurious-Free Dynamic Range at 102.4 kS/s

THD
- 0 dBFS input .... < –90 dB
- –20 dBFS input .... < –100 dB
- –60 dBFS input .... < –60 dB

IMD .... < –100 dB (CCIF 14 kHz + 15 kHz)

Crosstalk[1] (channel separation), f_{in} = 0 to 51.2 kHz
- Between channels 0 and 1, 2 and 3, 4 and 5, or 6 and 7
  - Shorted input .... < –90 dB
  - 1 kΩ load .... < –80 dB
- Other channel combinations
  - Shorted input .... < –100 dB
  - 1 kΩ load .... < –90 dB

Phase linearity .... < ±0.5°

Interchannel phase mismatch .... < f_{in} (in kHz) × 0.018° + 0.082°

Interchannel gain mismatch .... ±0.1dB

Onboard Calibration Reference

DC level .... 5.000 V ± 2.5 mV

Temperature coefficient .... ±5 ppm/°C max

Long-term stability .... ±20 ppm/$\sqrt{1{,}000\text{ h}}$

Signal Conditioning

Constant current source (software-controlled)
- Current .... 4 mA, ±5%
- Compliance .... 24 V
- Output impedance .... > 250 kΩ at 1 kHz
- Current noise .... < 500 pA/$\sqrt{\text{Hz}}$

[1] Measured with full-scale (±10 V) input.

Triggers

Analog Trigger

Source	ACH<0..7>
Level	–10 to +10 V, full scale, programmable
Slope	Positive or negative (software selectable)
Resolution	24 bits, nominal
Hysteresis	Programmable

Digital Trigger

Compatibility	TTL
Response	Rising or falling edge
Pulse width	10 ns, min

Bus Interface

Type	PXI Master/Slave

Power Requirements

+3.3 VDC	400 mA, max
+5 VDC	2,200 mA, max
+12 VDC	120 mA, max
–12 VDC	120 mA, max

Physical

Dimensions (not including connectors)	16 by 10 cm (6.3 by 3.9 in.) (1 3U CompactPCI slot)
Analog I/O connectors	SMB male
Digital trigger connector	SMB male

Environment

Operating temperature ....0 to +50 °C

Storage temperature range ....–25 to +85 °C

Relative humidity ....10% to 90%, no condensation

Calibration

Internal ....On software command; computes gain and offset corrections

Interval..Whenever temperature is different from temperature at last internal calibration by more than ±5 °C

External..Internal voltage reference read and stored in non-volatile memory

Interval..2 years

Warm-up time..15 minutes

Safety

Designed in accordance with IEC 61010-1, UL 3111-1, and CAN/CSA C22.2 No. 1010.1 for electrical measuring and test equipment.
For use at altitudes up to 2000 meters.
Installation category I[1]
Pollution degree 2

[1] Category I refers to equipment for which measures are taken to limit transient overvoltages to a level lower than that of local-level mains supplies, such as telecommunications and protected electronic circuits.

Electromagnetic Compatibility

EMC/EMI.. CE, C-Tick, and FCC Part 15 (Class A) Compliant

Electrical emissions................................ EN 55011 Class A at 10 m
FCC Part 15A above 1 GHz

Electrical immunity................................ Evaluated to EN 61326:1998, Table 1

Note This device should only be operated with shielded cabling for full EMC and EMI compliance. See the *Declaration of Conformity* for this product for any additional regulatory compliance information.

B

Technical Support Resources

Web Support

National Instruments Web support is your first stop for help in solving installation, configuration, and application problems and questions. Online problem-solving and diagnostic resources include frequently asked questions, knowledge bases, product-specific troubleshooting wizards, manuals, drivers, software updates, and more. Web support is available through the Technical Support section of `ni.com`

NI Developer Zone

The NI Developer Zone at `ni.com/zone` is the essential resource for building measurement and automation systems. At the NI Developer Zone, you can easily access the latest example programs, system configurators, tutorials, technical news, as well as a community of developers ready to share their own techniques.

Customer Education

National Instruments provides a number of alternatives to satisfy your training needs, from self-paced tutorials, videos, and interactive CDs to instructor-led hands-on courses at locations around the world. Visit the Customer Education section of `ni.com` for online course schedules, syllabi, training centers, and class registration.

System Integration

If you have time constraints, limited in-house technical resources, or other dilemmas, you may prefer to employ consulting or system integration services. You can rely on the expertise available through our worldwide network of Alliance Program members. To find out more about our Alliance system integration solutions, visit the System Integration section of `ni.com`

Worldwide Support

National Instruments has offices located around the world to help address your support needs. You can access our branch office Web sites from the Worldwide Offices section of `ni.com`. Branch office Web sites provide up-to-date contact information, support phone numbers, e-mail addresses, and current events.

If you have searched the technical support resources on our Web site and still cannot find the answers you need, contact your local office or National Instruments corporate. Phone numbers for our worldwide offices are listed at the front of this manual.

Glossary

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

Numbers/Symbols

°	degree
Ω	ohm
%	percent
+	positive of, or plus
–	negative of, or minus
/	per

A

A	amperes
A/D	analog-to-digital
AC	alternating current
AC coupled	allowing the transmission of AC signals while blocking DC signals
ADC	analog-to-digital converter—an electronic device, often an integrated circuit, that converts an analog voltage to a digital number

ADC resolution	the size of the discrete steps in the ADCs input-to-output transfer function; therefore, the smallest voltage difference an ADC can discriminate with a single measurement
ADE	application development environment—an application designed to make it easier for you to develop software. Usually, ADEs have a graphical user interface and programming tools to help with development. Examples of ADEs are LabVIEW, LabWindows/CVI, Visual Basic, and Visual C++.
alias	a false lower frequency component that appears in sampled data acquired at too low a sampling rate
amplification	a type of signal conditioning that improves accuracy in the resulting digitized signal and reduces noise
amplitude flatness	a measure of how close to constant the gain of a circuit remains over a range of frequencies
asynchronous	(1) hardware—a property of an event that occurs at an arbitrary time, without synchronization to a reference clock; (2) software—a property of a function that begins an operation and returns prior to the completion or termination of the operation
attenuate	to decrease the amplitude of a signal

B

bandwidth	the range of frequencies present in a signal, or the range of frequencies to which a measuring device can respond
bipolar	a signal range that includes both positive and negative values (for example, –5 V to +5 V)
buffer	temporary storage for acquired or generated data (software)
bus	the group of conductors that interconnect individual circuitry in a computer. Typically, a bus is the expansion vehicle to which I/O or other devices are connected. Examples of PC buses are the ISA and PCI bus.

C

C	Celsius
CCIF	*See* IMD.
channel	pin or wire lead to which you apply or from which you read the analog or digital signal. Analog signals can be single-ended or differential. For digital signals, you group channels to form ports. Ports usually consist of either four or eight digital channels.
clip	clipping occurs when an input signal exceeds the input range of the amplifier
clock	hardware component that controls timing for reading from or writing to groups
CMOS	complementary metal-oxide semiconductor
CMRR	common-mode rejection ratio—a measure of an instrument's ability to reject interference from a common-mode signal, usually expressed in decibels (dB)
code width	the smallest detectable change in an input voltage of a DAQ device
common-mode range	the input range over which a circuit can handle a common-mode signal
common-mode signal	the mathematical average voltage, relative to the computer's ground, of the signals from a differential input
conditional retrieval	a method of triggering in which you simulate an analog trigger using software. Also called software triggering.
counter/timer	a circuit that counts external pulses or clock pulses (timing)
coupling	the manner in which a signal is connected from one location to another
crosstalk	an unwanted signal on one channel due to an input on a different channel
current sourcing	the ability of a DAQ device to supply current for analog or digital output signals

D

DAQ	data acquisition—(1) collecting and measuring electrical signals from sensors, transducers, and test probes or fixtures and inputting them to a computer for processing; (2) collecting and measuring the same kinds of electrical signals with A/D and/or DIO devices plugged into a computer, and possibly generating control signals with D/A and/or DIO devices in the same computer
dB	decibel—the unit for expressing a logarithmic measure of the ratio of two signal levels: $dB = 20\log_{10} (V_1/V_2)$, for signals in volts
dBFS	absolute signal level compared to full scale
DC	direct current
DC coupled	allowing the transmission of both AC and DC signals
DDS clock	Direct Digital Synthesis clock—a type of clock source with an output frequency controlled by a digital input word
default setting	a default parameter value recorded in the driver. In many cases, the default input of a control is a certain value (often 0) that means *use the current default setting*. For example, the default input for a parameter may be *do not change current setting*, and the default setting may be *no AMUX-64T devices*. If you do change the value of such a parameter, the new value becomes the new setting. You can set default settings for some parameters in the configuration utility or manually using switches located on the device.
delta-sigma modulating ADC	a high-accuracy circuit that samples at a higher rate and lower resolution than is needed and (by means of feedback loops) pushes the quantization noise above the frequency range of interest. This out-of-band noise is typically removed by digital filters.
device	a plug-in data acquisition device, card, or pad that can contain multiple channels and devices. Plug-in boards, PCMCIA cards, and devices such as the DAQPad-1200, which connects to your computer parallel port, are all examples of DAQ devices. SCXI modules are distinct from devices, with the exception of the SCXI-1200, which is a hybrid.
differential input	an analog input consisting of two terminals, both of which are isolated from computer ground, whose difference is measured

differential measurement system	a way you can configure your device to read signals, in which you do not need to connect either input to a fixed reference, such as the earth or a building ground
digital trigger	a TTL level signal having two discrete levels—a high and a low level
DMA	direct memory access—a method by which data can be transferred to/from computer memory from/to a device or memory on the bus while the processor does something else. DMA is the fastest method of transferring data to/from computer memory.
DNL	differential nonlinearity—a measure in LSBs of the worst-case deviation of code widths from their ideal value of 1 LSB
down counter	performing frequency division on an internal signal
drivers	software that controls a specific hardware device such as a DAQ device or a GPIB interface device
DSA	dynamic signal acquisition
dynamic range	the ratio of the largest signal level a circuit can handle to the smallest signal level it can handle (usually taken to be the noise level), normally expressed in decibels

E

EEPROM	electrically erasable programmable read-only memory—ROM that can be erased with an electrical signal and reprogrammed
event	the condition or state of an analog or digital signal
external trigger	a voltage pulse from an external source that triggers an event such as A/D conversion

F

FIFO	first-in first-out memory buffer—the first data stored is the first data sent to the acceptor. FIFOs are often used on DAQ devices to temporarily store incoming or outgoing data until that data can be retrieved or output. For example, an analog input FIFO stores the results of A/D conversions until the data can be retrieved into system memory, a process that requires the servicing of interrupts and often the programming of the DMA controller. This process can take several milliseconds in some cases. During this time, data accumulates in the FIFO for future retrieval. With a larger FIFO, longer latencies can be tolerated. In the case of analog output, a FIFO permits faster update rates, because the waveform data can be stored on the FIFO ahead of time. This again reduces the effect of latencies associated with getting the data from system memory to the DAQ device.
filtering	a type of signal conditioning that allows you to attenuate unwanted portions of the signal you are trying to measure
f_{in}	input signal frequency
FIR	finite impulse response—a non recursive digital filter with linear phase
floating signal sources	signal sources with voltage signals that are not connected to an absolute reference or system ground. Also called nonreferenced signal sources. Some common example of floating signal sources are batteries, transformers, or thermocouples.
f_s	sampling frequency or rate

G

gain	the factor by which a signal is amplified, sometimes expressed in decibels
grounded measurement system	*See* SE.

H

h	hour
hardware	the physical components of a computer system, such as the circuit boards, plug-in boards, chassis, enclosures, peripherals, and cables
hardware triggering	a form of triggering where you set the start time of an acquisition and gather data at a known position in time relative to a trigger signal
high-impedance	in logic circuits designed to have three possible states—0, 1, and hi-Z—the hi-Z (high impedance) state effectively removes the output from its circuit, and can be used to simplify bus communication by wire-ANDing tri-state inputs
Hz	hertz—cycles per second. Specifically refers to the repetition frequency of a waveform.

I

I/O	input/output—the transfer of data to/from a computer system involving communications channels, operator interface devices, and/or data acquisition and control interfaces
IMD	intermodulation distortion—the ratio, in dB, of the total rms signal level of harmonic sum and difference distortion products, to the overall rms signal level. The test signal is two sine waves added together according to the following standards: CCIF—A 14 kHz sine wave and a 15 kHz sine wave added in a 1:1 amplitude ratio.
in.	inches
INL	integral nonlinearity—a measure in LSB of the worst-case deviation from the ideal A/D or D/A transfer characteristic of the analog I/O circuitry
input impedance	the measured resistance and capacitance between the input terminals of a circuit
interrupt	a computer signal indicating that the CPU should suspend its current task to service a designated activity
IRQ	interrupt request

K

k	kilo—the standard metric prefix for 1,000, or 10^3, used with units of measure such as volts, hertz, and meters
kS	1,000 samples

L

LabVIEW	laboratory virtual instrument engineering workbench
library	a file containing compiled object modules, each comprised of one of more functions, that can be linked to other object modules that make use of these functions. `nidaqmsc.lib` is a library that contains NI-DAQ functions. The NI-DAQ function set is broken down into object modules so that only the object modules that are relevant to your application are linked in, while those object modules that are not relevant are not linked.
linearity	the adherence of device response to the equation R = KS, where R = response, S = stimulus, and K = a constant
LSB	least significant bit

M

memory buffer	*See* buffer.
MITE	MXI Interface to Everything—a custom ASIC designed by National Instruments that implements the PCI bus interface. The MITE supports bus-mastering for high-speed data transfers over the PCI bus.
MS	million samples
MSB	most significant bit

N

NC	normally closed, or not connected
NI-DAQ	National Instruments driver software for DAQ hardware

noise	an undesirable electrical signal—Noise comes from external sources such as the AC power line, motors, generators, transformers, fluorescent lights, soldering irons, CRT displays, computers, electrical storms, welders, radio transmitters, and internal sources such as semiconductors, resistors, and capacitors. Noise corrupts signals you are trying to send or receive.
nonreferenced signal sources	signal sources with voltage signals that are not connected to an absolute reference or system ground. Also called floating signal sources. Some common example of nonreferenced signal sources are batteries, transformers, or thermocouples.
Nyquist frequency	a frequency that is one-half the sampling rate. *See* Nyquist Sampling Theorem.
Nyquist Sampling Theorem	the theorem states that if a continuous bandwidth-limited analog signal contains no frequency components higher than half the frequency at which it is sampled, then the original signal can be recovered without distortion

O

offset-binary format	a method of digitally encoding sound that represents the range of amplitude values as an unsigned number, with the midpoint of the range representing silence. For example, an 8-bit sound stored in offset-binary format would contain sample values ranging from 0 to 255, with a value of 128 specifying silence (no amplitude). *See* two's complement format.
operating system	base-level software that controls a computer, runs programs, interacts with users, and communicates with installed hardware or peripheral devices
oversampling	sampling at a rate greater than the Nyquist frequency

P

passband	the range of frequencies which a device can properly propagate or measure
PCI	Peripheral Component Interconnect—a high-performance expansion bus architecture originally developed by Intel to replace ISA and EISA. It is achieving widespread acceptance as a standard for PCs and work-stations; it offers a theoretical maximum transfer rate of 132 Mbytes/s.
PFI	programmable function input

Plug and Play devices	devices that do not require DIP switches or jumpers to configure resources on the devices—also called switchless devices
port	a communications connection on a computer or a remote controller
posttriggering	the technique used on a DAQ device to acquire a programmed number of samples after trigger conditions are met
ppm	parts per million
pretriggering	the technique used on a DAQ device to keep a continuous buffer filled with data, so that when the trigger conditions are met, the sample includes the data leading up to the trigger condition

Q

quantization error	the inherent uncertainty in digitizing an analog value due to the finite resolution of the conversion process
quantizer	a device that maps a variable from a continuous distribution to a discrete distribution

R

relative accuracy	a measure in LSB of the linearity of an ADC. It includes all non-linearity and quantization errors. It does not include offset and gain errors of the circuitry feeding the ADC.
resolution	the smallest signal increment that can be detected by a measurement system. Resolution can be expressed in bits, in proportions, or in percent of full scale. For example, a system has 12-bit resolution, one part in 4,096 resolution, and 0.0244% of full scale.
rise time	the difference in time between the 10% and 90% points of the step response of a system
rms	root mean square—the square root of the average value of the square of the instantaneous signal amplitude; a measure of signal amplitude

RSE	*See* SE.
RTSI bus	real-time system integration bus—the National Instruments timing bus that connects DAQ devices directly, by means of connectors on top of the boards, for precise synchronization of functions

S

s	seconds
S	samples
S/s	samples per second—used to express the rate at which a DAQ device samples an analog signal
sample counter	the clock that counts the output of the channel clock, in other words, the number of samples taken. On devices with simultaneous sampling, this counter counts the output of the scan clock and hence the number of scans.
SE	single-ended—a term used to describe an analog input that is measured with respect to a common ground
self-calibrating	a property of a DSA device that has an extremely stable onboard reference and calibrates its own A/D and D/A circuits without manual adjustments by the user
sensor	a device that responds to a physical stimulus (heat, light, sound, pressure, motion, flow, and so on), and produces a corresponding electrical signal
signal conditioning	the manipulation of signals to prepare them for digitizing
SMB	a type of coaxial connector
SNR	signal-to-noise ratio—the ratio of the overall rms signal level to the rms noise level, expressed in decibels
software trigger	a programmed event that triggers an event such as data acquisition
software triggering	a method of triggering in which you simulate an analog trigger using software. Also called conditional retrieval.
STC	system timing controller

switchless device	devices that do not require dip switches or jumpers to configure resources on the devices—also called Plug and Play devices
synchronous	(1) hardware—a property of an event that is synchronized to a reference clock; (2) software—a property of a function that begins an operation and returns only when the operation is complete
system noise	a measure of the amount of noise seen by an analog circuit or an ADC when the analog inputs are grounded

T

THD	total harmonic distortion—the ratio of the total rms signal due to harmonic distortion to the overall rms signal, in decibel or a percentage
THD+N	signal-to-THD plus noise—the ratio in decibels of the overall rms signal to the rms signal of harmonic distortion plus noise introduced
transducer	*See* sensor.
transfer rate	the rate, measured in bytes/s, at which data is moved from source to destination after software initialization and set up operations; the maximum rate at which the hardware can operate
TRIG1 (EXT_TRIG)	trigger 1 signal
trigger	any event that causes or starts some form of data capture
tri-state	logic circuitry designed to have three possible outputs—0, 1, and hi-Z. The hi-Z (high impedance) state effectively pulls the output out of its circuit, and can be used to simplify bus communication by wire-ANDing tri-state inputs.
TTL	transistor-transistor logic
TTL-compatible	operating in a nominal range of 0 to 5 VDC, with a signal below 1 V a logic low, and a signal above 2.4 V a logic high
two’s complement format	a system for digitally encoding sound that stores the amplitude values as a signed number, with silence represented by a sample with a value of 0. For example, with 8-bit sound samples, two's complement values would range from –128 to 127, with 0 meaning silence. *See* offset-binary format.

U

unbalanced differential input	an analog input channel consisting of two terminals, one of which is isolated from computer ground, and the other of which is grounded, whose difference is measured. *See* differential input.
undersampling	sampling at a rate lower than the Nyquist frequency—can cause aliasing

V

V	volts
V_{cc}	collector common voltage—power supply voltage
VDC	volts direct current
VI	virtual instrument—(1) a combination of hardware and/or software elements, typically used with a PC, that has the functionality of a classic stand-alone instrument; (2) a LabVIEW software module (VI), which consists of a front panel user interface and a block diagram program
V_{in}	volts in
V_{ref}	reference voltage

W

waveform	multiple voltage readings taken at a specific sampling rate

Index

O

P

R

S