DAQ

NI 435*x* User Manual

High-Precision Temperature and Voltage Meters

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Worldwide Technical Support and Product Information

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Depending on where it is operated, this Class A 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.

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

Consult the FCC Web site at `www.fcc.gov` for more information.

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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 marking 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 NI 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 is required to correct the interference at their 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.

Compliance to EU Directives

Readers in the European Union (EU) must refer to the manufacturer's Declaration of Conformity (DoC) for information* pertaining to the CE marking compliance scheme. The manufacturer includes a DoC for most hardware products except for those bought from OEMs. In addition, DoCs are usually not provided if compliance is not required, for example electrically benign apparatus or cables.

Refer to the Declaration of Conformity (DoC) for this product for any additional regulatory compliance information. To obtain the DoC for this product, visit `ni.com/hardref.nsf`, search by model number or product line, and click the appropriate link in the Certification column.

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* The CE marking Declaration of Conformity contains important supplementary information and instructions for the user or installer.

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About This Manual

This manual describes the electrical and mechanical aspects of the NI 435*x* family of instruments and contains information concerning device operation and programming.

Conventions

The following conventions appear 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, DIO<3..0>.
»	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.
♦	The ♦ symbol indicates that the following text applies only to a specific product, a specific operating system, or a specific software version.
✎	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. When this symbol is marked on the product, refer to the *Read Me First: Safety and Radio-Frequency Interference* document, shipped with the product, for precautions to take.
bold	Bold text denotes items that you must select or click 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 denotes text or characters that you should enter 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, operations, variables, filenames and extensions, and code excerpts.

NI 435*x*	Refers to all devices in the National Instruments 4350 and 4351 families.
NI 435*x* for PCI, PXI and USB	Refers to the all the devices in the National Instruments 4350 and 4351 families that have the PCI, PXI, and USB buses.
NI PCI-4351	Refers only to the NI 4351 for PCI bus computers.
NI PXI-4351	Refers only to the NI 4351 for PXI bus computers.
NI USB-4350	Refers only to the NI 4350 for computers that are USB compatible. You may have software that refers to this device as the DAQPad-4350.

Related Documentation

The *NI 435x User Manual* is one piece of the documentation set for the computer-based instrument system. Refer to the following documents at `ni.com/manuals` for additional information that is relevant to the NI 435*x* devices.

- *DAQ Quick Start Guide*
- *Read Me First: Safety and Radio-Frequency Interference*
- Software documentation—You may have application software and NI-DAQ software documentation. National Instruments application software includes LabVIEW, LabWindows™/CVI™, and VirtualBench-Logger. After you set up the hardware system, use either the application software documentation or the NI-DAQ documentation to help you write your application. If you have a large, complicated system, it is worthwhile to look through the software documentation before you configure the hardware.
- Accessory installation guides or manuals—If you are using accessory products, read the terminal block, adapter, and cable assembly installation guides. They explain how to physically connect the relevant pieces of the system. Consult these guides when you are making connections.

Note The latest NI 435*x* documentation is included on the NI-DAQ Device Documentation CD and may be installed at **Start»Programs»National Instruments» NI-DAQ**. You should refer to this location for all NI 435*x* documentation. Old versions of the NI 435*x* documentation are also installed at **Start»Programs»National Instruments 435x**, but these documents are *not* the most up-to-date documentation for the NI 435*x* devices.

1

Introduction

This chapter describes the NI 4350/4351 (NI 435*x*) family of high-precision temperature and voltage meters and describes the optional software and equipment.

About the NI 435*x* High-Precision DAQ Devices

Thank you for purchasing an NI 435*x* high-precision DAQ device. The NI 435*x* family consists of high-precision DAQ devices for each of the following buses: Universal Serial Bus (USB), PXI, and PCI.

The NI 435*x* high-precision DAQ devices feature accurate thermocouple and DC voltage measurements. You also can take temperature measurements with resistance temperature detectors (RTDs) or thermistors, resistance measurements using the built-in precision current sources, and current measurements using external shunt resistors. You can use the NI 435*x* with a PC to make the same measurements you would with standard benchtop instruments such as data loggers and digital multimeters (DMMs).

The NI 435*x* contains a 24-bit sigma-delta analog-to-digital converter (ADC) with differential analog inputs. The low leakage construction, along with analog and digital filtering, provides excellent resolution, accuracy, and noise rejection. With software-programmable ground-referencing, you can reference the floating signal without compromising voltage measurements even if the floating signal is ground-referenced. With software-programmable open-thermocouple detection, you can quickly detect a thermocouple that may have broken before or during measurement.

You can measure up to a total resistance of 600 kΩ using the built-in 25 µA precision current source on the NI USB-4350, NI PCI-4351, and NI PXI-4351 and up to 15 kΩ with the additional built-in 1 mA precision current source on the NI PXI-4351 and NI PCI-4351. In addition, the NI 435*x* devices have programmable TTL-compatible digital I/O (DIO) for monitoring TTL-level inputs, interfacing with external devices, and generating alarms.

The NI 435*x* DAQ devices are Plug and Play compatible and are fully software calibrated. Because the NI 435*x* devices work with a variety of operating systems, you can develop applications that scale across several platforms.

A system based on NI 435*x* devices offers flexibility, performance, and compact size, making it ideal for service, repair, and manufacturing and for use in industrial and laboratory environments. The NI 435*x* devices, used with the computer, are versatile, cost-effective platforms for high-resolution measurements.

Detailed specifications for the NI 435*x* DAQ devices are in Appendix A, *Specifications*.

Using PXI with CompactPCI

Using PXI-compatible products with standard CompactPCI products is an important feature provided by the PXI Specification.

The NI PXI-4351 does not have connections to reserved lines on the CompactPCI J2 connector. Therefore, you can use the NI PXI-4351 in a CompactPCI system that uses J2 connector lines for purposes other than PXI.

Configuration

The NI 435*x* is a completely software-configurable, Plug and Play instrument. The Plug and Play services query the instrument and allocate the required resources, and then the operating system enables the instrument for operation.

Note Refer to the *DAQ Quick Start Guide* for detailed configuration information.

NI 435*x* Software Selection Chart

Figure 1-1 shows the choices you have for programming the NI 435*x*. Refer to the *Software Options for the NI 435x* section for more information on each software package.

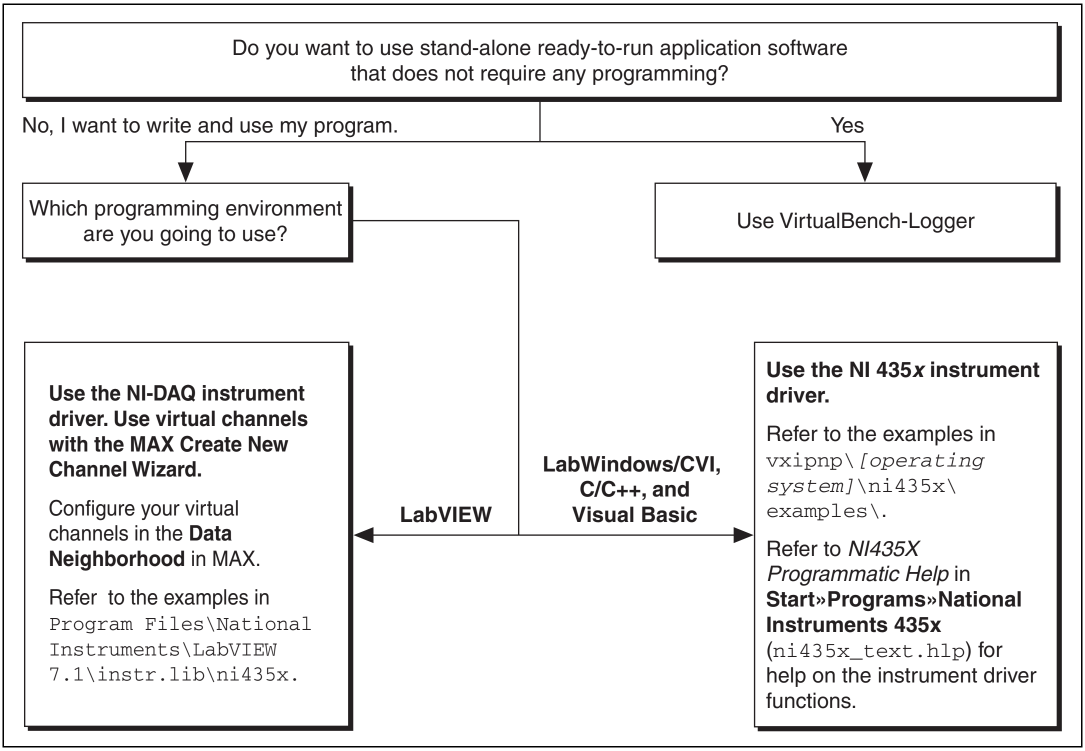

Figure 1-1. Software Choices for the NI 435*x*

Software Options for the NI 435*x*

You have several options to choose from to program and use the NI 435*x*. You can use LabVIEW, LabWindows/CVI, Visual Basic, or VirtualBench-Logger. This section explains the software choices available for the NI 435*x* in more detail.

What Is VirtualBench-Logger?

VirtualBench-Logger is a high-performance, easy-to-use, virtual instruments application program for use with the NI 435*x* devices.

What Is LabVIEW?

LabVIEW is a powerful graphical programming language for building instrumentation systems featuring interactive graphics and state-of-the-art user interface. With LabVIEW, you can quickly create front panel user interfaces, giving you interactive control of the software system. To specify the functionality, you intuitively assemble block diagrams—a natural design notation for engineers and scientists. LabVIEW has all of the same development tools and language capabilities of a standard language such as C—looping and Case structures, configuration management tools, and compiled performance.

The LabVIEW Data Acquisition VI Library, a series of VIs for using LabVIEW with National Instruments DAQ hardware, is included with LabVIEW.

Use NI-DAQ with LabVIEW to control the NI 435*x*.

What Is LabWindows/CVI?

LabWindows/CVI is an interactive ANSI C programming environment designed for automated test applications. LabWindows/CVI enhances traditional programming languages.

The LabWindows/CVI Data Acquisition Library, a series of functions for using LabWindows/CVI with National Instruments DAQ hardware, is included with the NI-DAQ kit. The LabWindows/CVI Data Acquisition library is functionally equivalent to NI-DAQ.

Use the NI 435*x* instrument driver with LabWindows/CVI.

What Is the NI 435*x* Instrument Driver?

An instrument driver packages instrument capabilities as a set of standard functions. Each function corresponds to a programmatic operation such as configuring, reading from, writing to, and starting and stopping the measurements. An instrument driver reduces the program development time and simplifies instrument control by eliminating the need to learn complex programming protocol for each instrument.

The NI 435*x* instrument driver provides programmability in a standard instrument driver format. The instrument driver application programming interface (API) was designed after a traditional, full-featured data logger instrument driver. The NI 435*x* instrument driver is *VXI Plug and Play* compliant and also contains the source code, so you can examine and modify it. The NI 435*x* instrument driver works with LabVIEW, LabWindows/CVI, or conventional programming languages such as C, C++, and Visual Basic.

For more details on what an instrument driver is, visit `www.vxipnp.org`. It is not necessary to use the NI 435*x* instrument driver functions in LabVIEW. NI-DAQ provides support for all NI 435*x* functions.

Whether you are using the NI 435*x* instrument driver, VirtualBench-Logger, LabVIEW, LabWindows/CVI, or Visual Basic, the application uses NI-DAQ, as illustrated in Figure 1-2.

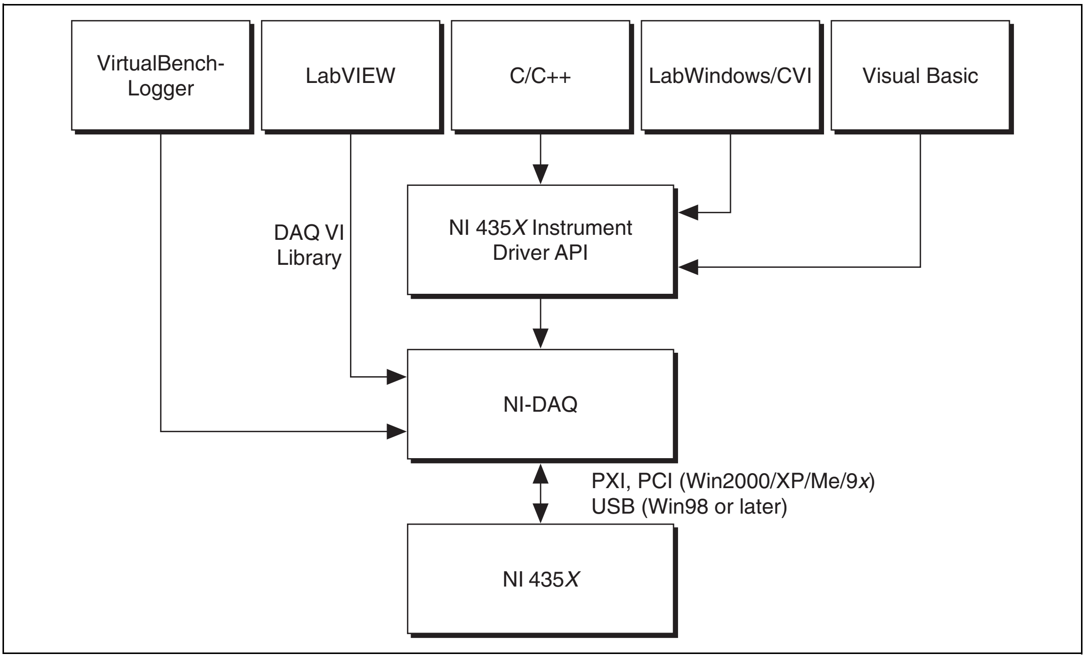

Figure 1-2. The Relationship Among the Programming Environment, NI 435*x* Instrument Drivers, NI-DAQ, and the NI 435*x*

What Is the MAX Create New Channel Wizard?

In the past, data acquisition system developers spent a large amount of time defining the signal types, connections, transducer equations, and unit conversions before beginning development of the actual system. For example, if you are using thermocouples, you must perform additional cold-junction compensation (CJC) calculations to convert raw voltage values into actual temperature readings, and then apply scaling factors that depend on the type of thermocouple used. From there, you may need to use additional code to convert the temperature into proper units, such as degrees Celsius, Fahrenheit, or kelvin.

With the Create New Channel Wizard in Measurement & Automation Explorer (MAX), you simply fill in the blanks to define an input signal by specifying its name and description, the type of transducer being used, any scaling factors or equations required, CJC settings, and unit conversion factors. The channel name, also known as a *virtual channel*, is then referenced throughout the application—with all of the conversion processes performed transparently.

Notes Using virtual channels and NI-DAQ, you can completely control the board without the NI 435*x* instrument driver. You cannot use the Create New Channel Wizard with the NI 435*x* instrument driver.

To configure virtual channels in Traditional NI-DAQ, refer to the *Step 15. Configure Channels and Tasks* section of the *DAQ Quick Start Guide.*

Refer to the examples recommended for use with the Create New Channel Wizard in the chart shown in Figure 1-1.

Installing the Software and Hardware

For software and hardware installation instructions, refer to the *DAQ Quick Start Guide* that shipped with your device or at `ni.com/manuals`.

LED Patterns

When you connect the NI 4350 (USB) to your PC, the computer should detect the NI 4350 (USB) immediately. When the computer recognizes the NI 4350 (USB), the LED on the front panel blinks or lights up, depending on the status of your device. If the LED comes on after the NI 4350 (USB) is connected to the computer, it is functioning properly. If the LED remains off or blinks, refer to Table 1-1. The LED blinks on and off for one second each for as many times as necessary, then waits three seconds before repeating the cycle.

Table 1-1. LED State Patterns for the NI 4350 (USB) States[1]

LED	NI USB-4350 State	Description
On	Configured state	The NI USB-4350 is configured.
Off	Off or in the low-power, suspend mode	The NI USB-4350 is powered off or in the low-power, suspend mode.
1 blink	Attached state	The NI USB-4350 is recognized, but not configured.
2 blinks	Addressed state	The host computer detects the NI USB-4350, but cannot configure it because NI-DAQ is improperly installed or system resources are unavailable. Check the software installation.
3 blinks	Power supply failure	The internal power supply shut down. Refer to the *Power Considerations for the NI USB-4350* section of the *NI 435X User Manual* for more information.
4 blinks	General error state	Contact NI. Refer to Appendix C, *Technical Support and Professional Services*, for contact information.

[1] The LED blinks in one-second intervals during each cycle. The LED then waits three seconds before repeating the cycle.

Optional Equipment

NI offers a variety of products to use with the NI 435*x*, including cables, connector blocks, terminal blocks, and other accessories, as follows:

- Cables and adapters with thermocouple miniconnectors
- Connector blocks including isothermal connector blocks
- Cables and cable accessories, shielded and ribbon

For more specific information about these products, refer to the NI catalog or Web site at `ni.com` or call the office nearest you.

Power Considerations for the NI USB-4350

The NI USB-4350 is designed to remain powered only when the USB cable connects it to the host PC, and the PC is powered on.

The NI USB-4350 is designed to run in a stand-alone mode, drawing power only from the USB cable. There are circumstances when the NI USB-4350 may require more power than the USB power supply can safely deliver. If the NI USB-4350 tries to draw more than the allowed current from the USB power supply, internal protection circuitry turns off most of the circuitry in the NI USB-4350 to protect the USB supply. This over-current condition makes the LED blink in the power supply overload pattern described in Table 1, *LED Patterns for the NI USB-4350 States*, of the *Where to Start with the NI 435x* document.

Note When the NI USB-4350 powers off, any data acquisition in progress is aborted and the data is lost.

The host computer has the ability to go into a power-saving *suspend* mode and, during this time, the NI USB-4350 also can either go into a low-power mode or remain in a fully-powered, static state. This low-power mode is important if you are using a laptop or if power consumption is a concern.

In the powered, static state of the NI USB-4350, all digital outputs are static at a fixed voltage.

Note Refer to the NI-DAQ function `Set_DAQ_Device_Info` in the Traditional NI-DAQ documentation or to the *Set DAQ Device Information (Device Setting VI)* in the *LabVIEW VI, Function, & How-to Help* to change the settings that determine the behavior of the NI USB-4350 during suspend mode. The default setting is to remain fully powered.

Safety Information

For safety information that is relevant to the NI 435*x* devices, refer to the *Read Me First: Safety and Radio-Frequency Interference* document that shipped with your device or to `ni.com/manuals`.

2

Operating the NI 435*x* Device

This chapter describes how to use the NI 435*x* device and includes operation tips on taking measurements with temperature sensors such as thermocouples, RTDs, and thermistors, as well as measuring voltages and resistances.

Caution Refer to the *Read Me First: Safety and Radio-Frequency Interference* document before removing equipment covers or connecting/disconnecting any signal wires.

Warming up the NI 435*x* Device

To minimize the effects of thermal drift and to ensure the specified accuracy, allow the NI 435*x* device to warm up for at least 10 minutes after startup before taking measurements. To maximize the relative accuracy of measurements, take all measurements after the NI 435*x* device warms up for about 30 minutes.

Choosing a Measurement Mode

Each analog input channel can be configured in two possible measurement modes—the volts mode or the 4-wire ohms mode. Use the volts mode for thermocouple and voltage measurements and the 4-wire ohms mode for RTD, thermistor, and resistance measurements using the built-in current source to provide excitation for the resistive sensors. In the 4-wire ohms mode, the software returns the resistance value by dividing the voltage measured by the value of the current source stored onboard.

Note VirtualBench-Logger, the NI 435*x* instrument driver, and the MAX Create New Channel Wizard select the measurement mode automatically, depending on the sensor type you specify.

Choosing a Range

The volts mode has six bipolar input ranges: ±625 mV, ±1.25 V, ±2.5 V, ±3.75 V, ±7.5 V, and ±15 V.

The 4-wire ohms mode has six corresponding input ranges when used with the built-in 25 μA current source: 25 kΩ, 50 kΩ, 100 kΩ, 150 kΩ, 300 kΩ, and 600 kΩ, and 625 Ω, 1.2 kΩ, 3.75 kΩ, 7.5 kΩ, and 15 kΩ with the built-in 1 mA current source on the NI PXI-4351 or NI PCI-4351. Choose the smallest range for the best measurement results. When scanning multiple channels, the NI 435*x* uses a single range, which is the widest range of any channel in the scan list.

Note With VirtualBench-Logger or the MAX Create New Channel Wizard, you can specify the range based on the sensor type in engineering units appropriate to the sensor. This sensor range is used to automatically set the actual hardware range.

Choosing a Reading Rate

The *reading rate* is the rate at which the NI 435*x* takes a new measurement. This rate has a direct relationship with the digital filter built into the ADC used in the NI 435*x*.

The digital filter has the characteristics shown in Figure 2-1. You can set the frequency of the first notch of this filter to 10 Hz, 50 Hz, or 60 Hz. Setting the notch filter at one of these frequencies rejects any noise at that frequency as well as at all of its multiples.

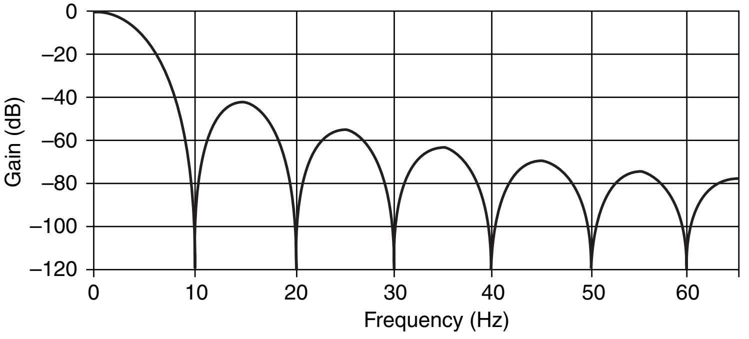

Figure 2-1. Digital Filter Characteristics for 10 Hz Setting

In single-channel measurements, the reading rate is the same as the notch filter frequency—10, 50, or 60 readings/s. In multiple-channel measurements, the reading rates adjust to allow the analog and digital filters to settle to the specified accuracy.

Note To determine the reading rate per channel when scanning multiple channels, divide the multiple-channel measurement reading rate in Table 2-1 by the number of channels in the scan.

In certain applications, such as resistance measurements above 25 kΩ or voltage measurements with more than 25 kΩ of source resistance, you should measure the same channel for up to 1 s, then switch to another channel to achieve the specified accuracy. This extra time allows the input filter capacitors of the NI 435*x* devices to fully charge or discharge.

To optimize measurement accuracy and minimize the noise level, choose the 10 Hz notch filter setting.

In practice, most of the noise encountered in measurements occurs at harmonics (multiples) of the local powerline frequency (PLF). Table 2-1 shows which programming settings to use to reject harmonics of particular frequencies.

Table 2-1. Filtering and Sample Rates

NI-DAQ or VirtualBench-Logger	NI 435*x* Instrument Driver		Equivalent Filter Setting		Harmonics of Noise Frequencies Rejected (Hz)	Single-Channel Measurement Reading Rate (readings/s)	Multiple-Channel Measurement Reading Rate (readings/s)	
Notch Filter Frequency Setting (Hz)	**PLF* (Hz)**	**Reading Rate**	**PLC****	**PLF* (Hz)**				
10	50 or 60	slow	5 6 40	50 60 400	10, 50, 60, and 400	10	2.8	1.4***
50	50	fast	1 8	50 400	50 and 400	50	8.8	2.1***
60	60	fast	1	60	60	60	9.7	2.1***

* Powerline frequency
** Number of powerline cycles used for filtering
*** For resistance ranges of 50 kΩ and higher

Note These rates were obtained without auto-zeroing and cold-junction compensation.

Knowing the Signal Source

For accurate measurements, you must determine whether the signal source is floating or ground-referenced.

Floating Signal Source

A *floating signal source* is one that is not connected in any way to the building ground system but has an isolated ground-reference point. Examples of floating signal sources are thermocouples with ungrounded junctions and outputs of transformers, batteries, battery-powered devices, optical isolators, and isolation amplifiers.

Ground-Referenced Signal Source

A *ground-referenced signal source* is one that is connected in some way to the building system ground. Therefore, it is already connected to a common ground point with respect to the NI 435*x*, assuming that the computer is plugged into the same power system. Examples of ground-referenced signal sources include the following:

- Thermocouples with grounded or exposed junctions connected to grounded test points
- The outputs of plug-in devices with nonisolated outputs
- Voltage across RTDs, thermistors, or resistors that you may be measuring using the built-in current sources of the NI 435*x*

Using Programmable Ground-Referencing

The NI 435*x* devices have software-programmable ground-referencing on every channel, which you can use to ground-reference a floating signal source. This connects CH– to ground through a 10 MΩ resistor and provides a ground-reference for the floating signal source. Even if the signal source is ground-referenced, this resistance minimizes the effects of ground-loops, as long as the source impedance and the lead wire resistance is less than 100 Ω . Thus, you can take accurate measurements even if you are uncertain whether the signal source is floating or ground-referenced.

Because you can set ground-referencing on a channel-by-channel basis, you can have ground-referenced signal sources connected to some channels and floating signal sources connected to other channels in the same measurement setup. Table 2-2 summarizes the settings to use for ground-referencing.

Table 2-2. Using Programmable Ground-Referencing

Signal Source	Programmable Ground-Referencing
Floating	On
Ground-referenced	Off

Note The default setting for programmable ground referencing is On in volts measurement mode, and Off in 4-wire ohms mode.

Using Programmable Open-Thermocouple Detection

The NI 435*x* devices have software-programmable, open-thermocouple detection on every channel, which you can use to detect an open or broken thermocouple. This feature connects CH+ to +2.5 V through a 10 MΩ resistor. This resistor acts as a pull-up resistor and, consequently, the voltage between CH+ and CH– rises rapidly above 100 mV if the thermocouple breaks open. All thermocouples functioning under normal conditions generate a voltage of less than 100 mV, even at very high temperatures, which makes this conclusion possible. You can detect this voltage level in software and conclude that the thermocouple is open.

To understand how setting open-thermocouple detection affects the accuracy of measurements, refer to the *Using Programmable Open-Thermocouple Detection* section. You can set open-thermocouple detection on a channel-by-channel basis. Table 2-3 summarizes the settings you should use for open-thermocouple detection.

Table 2-3. Using Programmable, Open-Thermocouple Detection

Signal Source	Programmable Open-Thermocouple Detection
Thermocouples	On or Off
Voltage signal sources other than thermocouples	Off
RTDs, thermistors, and resistors connected to the built-in current source	Off

Note The default setting for programmable open-thermocouple detection in volts and 4-wire ohms measurement modes is Off.

Measuring Temperature with Thermocouples

The thermocouple is the most popular transducer for measuring temperature. Because the thermocouple is inexpensive, rugged, and can operate over a very wide range of temperatures, it is a versatile and useful sensor.

A thermocouple operates on the principle that the junction of two dissimilar metals generates a voltage that varies with temperature, or thermal electromotive force (EMF). However, just measuring this voltage is not sufficient because connecting the thermocouple to the NI 435*x* accessory creates the *reference junction* or *cold-junction*, shown in Figure 2-2. These additional junctions act as thermocouples and produce their own voltages. Thus, the final measured voltage, $V_{measured}$, includes both the thermocouple voltage, $V_{thermocouple}$, and the cold-junction voltage, $V_{cold\text{-}junction}$. The method of compensating for these unwanted cold-junction voltages is called *cold-junction compensation*.

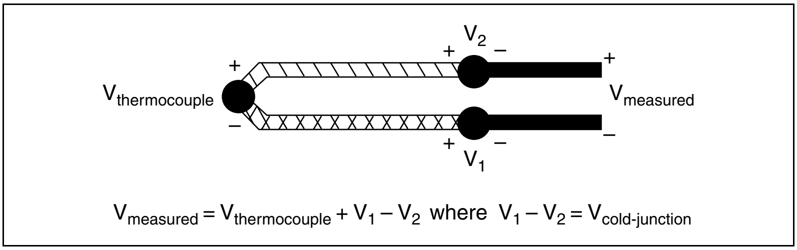

Figure 2-2. Effect of the Cold-Junction

With the NI 435*x*, you can perform cold-junction compensation in software. To do this, you can use the thermistor temperature sensor on the NI 435*x* accessory to measure the ambient temperature at the cold-junction and compute the appropriate compensation for the unwanted thermoelectric voltages using software. The cold-junction sensor is on analog channel 0 on the PSH32-TC6, TC-2190, CB-27T, TBX-68T, and CB-68T.

You have several options for performing cold-junction compensation:

- If you are using VirtualBench-Logger or the NI 435*x* instrument driver, the software automatically performs cold-junction compensation on all channels configured as thermocouple channels.
- If you are using LabVIEW and MAX virtual channels, the software includes examples that perform these temperature-to-voltage and voltage-to-temperature conversions for the cold-junction thermistor and various types of thermocouples based on the National Institute of Standards and Technology (NIST) standard reference tables. These examples are located in the DAQ analog input example library and have NI 435*x* in their titles.
- If you are not using either of the previous software options, complete the following steps to perform cold-junction compensation.
    1. Measure the resistance of the thermistor cold-junction sensor, $R_{thermistor\ cold\text{-}junction}$, and compute the cold-junction temperature, $T_{cold\text{-}junction}$, using the thermistor resistance-temperature conversion formula.
    2. From this temperature of the cold-junction, $T_{cold\text{-}junction}$, compute the equivalent thermocouple voltage, $V_{cold\text{-}junction}$, for this junction using a standard thermocouple conversion formula.

3. Measure the voltage, $V_{measured}$, and add the cold-junction voltage, $V_{cold\text{-}junction}$, computed in step 2.
4. Convert the resulting voltage to temperature using a standard thermocouple conversion formula.

Connecting the Thermocouple

The NI 435*x* accessories—the TC-2190, TBX-68T, and CB-68T for the NI 435*x* for PXI, PCI, and USB—are designed to be used with thermocouples. Consult the accessory installation guide for instructions on how to connect the thermocouples. To make accurate measurements, make sure that the common-mode voltage of the thermocouple is within the input common-mode limits of the selected input range.

Caution To prevent possible safety hazards, the maximum voltage between any of the analog inputs and the computer ground should *never* exceed ±42 VDC when the NI 435*x* is powered on and ±17 VDC when the NI 435*x* is powered off.

The NI 435*x* analog inputs are protected against damage from voltages within ±42 VDC in all ranges when powered on and ±17 VDC when the NI 435*x* device is powered off. Never apply voltages above these levels to the inputs.

Input Ranges

Choose the ±625 mV range in volts mode when you are measuring thermocouples. You can measure both the thermocouples and the thermistor cold-junction sensor on the NI 435*x* accessory in the same scan by choosing the 25 kΩ range for measuring the thermistor. These ranges offer the best resolution, noise rejection, and accuracy.

Note If scanning thermocouples and other transducers, the NI 453*x* device uses the widest range for all channels.

Optimizing Measurements

To make accurate thermocouple measurements, set the onboard programmable ground-referencing and open-thermocouple detection appropriately. Also consider problems associated with AC noise effects, thermal EMF, and other errors as discussed in the following sections.

Auto-Zero

Auto-zero is a method that instruments use to remove any offset errors in the measurement. Analog channel 1 (CH1) on the PSH32-TC6, CB-27T, TC-2190, TBX-68T, and CB-68T is dedicated for auto-zero. CH1+ is connected to CH1– on these accessories. You can measure the voltage offset on this auto-zero channel and subtract it from the voltage measurements on other channels. This way you can compensate for any residual offset error the NI 435*x* may have. This compensation is especially useful when the NI 435*x* device is operating at an ambient temperature other than that of calibration (23 °C typical).

Note When measuring the transducer channel with auto-zero and/or cold-junction compensation, the NI 435*x* device operates at its multi-channel rate. Refer to Table 2-1 for this rate.

Programmable Ground-Referencing

If you determine that the thermocouple is ground-referenced, switch off ground-referencing on that channel.

If you determine that the thermocouple is floating, switch on ground-referencing on that channel. Otherwise, the thermocouple inputs may float out of the input common-mode limits of the NI 435*x* device.

On all the NI 435*x* accessories used with thermocouples, analog channel CH0 is dedicated to the thermistor cold-junction sensor. The built-in current source return terminal I_{EX-} or I_{EX0-} is tied to –2.5 V through a resistor. This –2.5 V references any resistor excited by the current source to ground. Since this current source excites the cold-junction thermistor, CH0 is automatically ground-referenced. Therefore, when measuring the voltage across this thermistor, always switch off programmable ground-referencing on CH0. Otherwise, the leakage current flowing into the thermistor may cause erroneous measurements in all the channels that use the current source. Current source terminal I_{EX1-} also is tied to –2.5 V through a resistor.

Note When using VirtualBench-Logger or the MAX virtual channels, the ground-referencing switch on the cold-junction sensor channel and auto-zero channel is automatically set appropriately.

Programmable Open-Thermocouple Detection

To detect open or broken thermocouples, switch on open-thermocouple detection on that channel. Then, if the thermocouple breaks, the voltage on that channel rises rapidly above 100 mV, at which point you can conclude that the thermocouple is open.

Notice that when open-thermocouple detection is on and the floating thermocouple is not broken, a very small amount of current is injected into the thermocouple. The value of the current is approximately 125 nA when ground-referencing also is on. If the thermocouple is very long, the injected current can cause an error voltage to develop in the lead resistance of the thermocouple that is indistinguishable from the thermocouple voltage you are measuring. You can estimate this error voltage with the following formula:

$$\text{error voltage} = \text{resistance of thermocouple} \times 125 \text{ nA}$$

For example, if you use a 100 ft long, 24 AWG J-type thermocouple with a resistance of 0.878 Ω per double foot, the error voltage generated is approximately 11 µV, which corresponds to about 0.2 °C. If this error is too large for the measurement, you can reduce the error by reducing the thermocouple resistance or by lowering the length of the thermocouple or gauge of the wire (use a wire of larger diameter). Alternatively, you can switch off the open-thermocouple detection to eliminate the current injected into the thermocouple.

AC Noise Effects

The NI 435*x* rejects AC voltages as specified in normal mode rejection (NMR) in Appendix A, *Specifications*. However, if the amplitudes of the AC voltages are large compared to the DC voltages, or if the peak value (AC plus DC) of the measured voltage is outside the input range, the NI 435*x* may exhibit additional errors. To minimize these errors, keep the thermocouples, the NI 435*x*, and its accessories away from strong AC magnetic sources, and minimize the area of the loop formed by the thermocouple wires connected to the accessory. Choose the notch filter frequency of 10 Hz for the best AC noise rejection. If the peak value of the measured voltage is likely to exceed the selected input range, select the next higher input range.

Thermal EMF

When using thermocouples, any thermal EMFs introduce error other than those at the hot junction (where the thermocouple measures the test point temperature) and at the cold junction on the accessory.

To minimize thermal EMFs, use wires made of the same material as the thermocouple when extending the length of the thermocouple. Also, minimize temperature gradients in the space enclosing the thermocouples, the NI 435*x*, and its accessories.

Measuring DC Voltage

Connecting the DC Voltage Signal

The NI 435*x* accessories—the TBX-68T, CB-68T, and TBX-68 for the NI 435*x* for USB, PXI, and PCI—are designed to be used with any DC voltage signal. Consult the accessory installation guide for instructions on how to connect the voltage signals.

The NI 435*x* analog inputs are protected against damage from voltages within ±42 VDC in all ranges when powered on and ±17 VDC when the NI 435*x* is powered off. Never apply voltages above these levels to the inputs.

Caution To prevent possible safety hazards, the maximum voltage between any of the analog inputs and the computer ground should *never* exceed ±42 VDC when the NI 435*x* is powered on and ±17 VDC when the NI 435*x* is powered off.

Input Ranges

The NI 435*x* has six bipolar input ranges available for measuring DC voltage. These ranges are ±625 mV, ±1.25 V, ±2.5 V, ±3.75 V, ±7.5 V, and ±15 V. The NI 435*x* can measure DC voltage to the specified accuracy as long as the voltage is within the selected input range. To get the best resolution, noise rejection, and accuracy, choose the smallest possible range. Make sure that each signal input to CH+ and CH– is within the input common-mode limits of this input range. The input common-mode limits are ±2.5 V and ±15 V for the lower three and higher three input ranges, respectively.

Note If scanning voltages in different ranges, the NI 435*x* uses the widest range for all channels.

Optimizing Measurements

To make accurate voltage measurements, program the onboard ground-referencing and open-thermocouple detection appropriately. Also consider problems associated with AC noise effects, thermal EMFs, and other errors as discussed in the following sections.

Auto-Zero

Auto-zero is a method that instruments use to remove offset errors in the measurement. Analog channel 1 (CH1) on the CB-27T, TBX-68T, and CB-68T is dedicated for auto-zero. CH1+ is connected to CH1– on these accessories. When using a CB-27 or TBX-68 accessory for RTDs, connect CH– to CH+ (any channel) to make that channel useful for auto-zero. You can measure the voltage offset on this auto-zero channel and subtract it from the voltage measurements on other channels. This way, you can compensate for any residual offset error the NI 435*x* may have. This compensation is especially useful when the NI 435*x* is operating at an ambient temperature other than that of calibration (23 °C typical).

Note When measuring the transducer channel with auto-zero, the NI 435*x* operates at its multi-channel rate. Refer to Table 2-1 for this rate.

Programmable Ground-Referencing

If you determine that the signal source is ground-referenced, switch off ground-referencing on that channel.

If you determine that the signal source is floating, switch on ground-referencing on that channel. Otherwise, the inputs may float out of the input common-mode limits of the NI 435*x*.

When you use the CB-27T, TBX-68T, and CB-68T accessories, always switch on ground-referencing on CH1. Doing this ground-references the auto-zero channel.

Note When using the MAX virtual channels, along with the NI 435*x* accessories—PSH32-TC6, CB-27T, CB-68T, TC-2190, or TBX-68T—the ground-referencing switch on the auto-zero channel is automatically set appropriately.

Programmable Open-Thermocouple Detection

When you measure voltage signals other than thermocouples, always switch off the onboard open-thermocouple detection.

Source Impedance

For best results, maintain the source impedance and the lead wire resistance of the signal at less than 100 Ω. If either of these is greater than 25 kΩ, you should measure the same channel for up to 1 s, then switch to another channel to achieve the specified accuracy.

AC Noise Effects

The NI 435*x* rejects AC voltages as specified in Appendix A, *Specifications*. However, if the amplitudes of the AC voltages are large compared to the DC voltages, or if the peak value (AC plus DC) of the measured voltage is outside the input range, the NI 435*x* may exhibit additional errors. To minimize these errors, keep the signal source, the NI 435*x*, and its accessories away from strong AC magnetic sources, and minimize the area of the loop formed by the wires that connect the signal source with the accessories. Choosing the notch filter frequency of 10 Hz provides the best AC noise rejection. If the peak value of the measured voltage is likely to exceed the selected input range, select the next higher input range.

Thermal EMF

Thermoelectric potentials or thermal EMFs are voltages generated at the junctions of dissimilar metals and are functions of temperature. Thermal EMFs in the source generating the signal can introduce errors in measurements that change with variations in temperature.

To minimize thermal EMFs, use copper wires to connect the signal to the NI 435*x* accessory. Avoid using dissimilar metal wires in connections. Also, minimize temperature gradients in the space enclosing the signal source, the NI 435*x*, and its accessories.

Measuring Temperature with RTDs and Thermistors and Measuring Resistance

RTDs and thermistors are essentially resistors whose resistance varies with temperature. Therefore, measurement techniques for RTDs, thermistors, and resistors are quite similar. All techniques involve exciting the resistor with a current or a voltage source and measuring the resulting voltage or current, respectively, developed in the resistor.

With the NI 435*x*, you can excite the resistor with the built-in precision current source and measure the resulting voltage. When using virtual channels with LabVIEW, set the measurement mode to **Resistance** or **RTD**. When using VirtualBench-Logger, set the measurement mode to **Resistance**, **RTD**, or **Thermistor**. When using the NI 435*x* instrument driver, set the measurement mode to **Resistance**. These modes return the measurements in units of resistance (ohms) by dividing the measured voltage with the calibrated value of the precision current source stored onboard.

Introduction to RTDs

An RTD is a temperature-sensing device whose resistance increases with temperature. An RTD consists of a wire coil or deposited film of pure metal. RTDs can be made of different metals and can have different resistances, but the most popular RTD is made of platinum and has a nominal resistance of 100 Ω at 0 °C.

RTDs are known for their excellent accuracy over a wide temperature range. Some RTDs have accuracy as high as 0.01 Ω (0.026 °C) at 0 °C. RTDs are also extremely stable devices. Common industrial RTDs drift less than 0.1 °C/year, and some models are stable to within 0.0025 °C/year.

RTDs can be difficult to measure because they have relatively low resistance (100 Ω) that changes only slightly with temperature (less than 0.4 Ω/°C). To accurately measure these small changes in resistance, you may need to use special configurations that minimize errors from lead wire resistance.

Relationship of Resistance and Temperature in RTDs

Compared to other temperature devices, the output of an RTD is relatively linear with respect to temperature. The temperature coefficient, called *alpha* (α), differs between RTD curves. Although various manufacturers may specify α differently, α is most commonly defined as the change in RTD resistance from 0 to 100 °C, divided by the resistance at 0 °C, divided by 100 °C as follows:

$$\alpha\ (\Omega/\Omega/^\circ\mathrm{C}) = [(R_{100} - R_0)/R_0]/100\ ^\circ\mathrm{C}$$

where R_{100} is the resistance of the RTD at 100 °C, and R_0 is the resistance of the RTD at 0 °C.

For example, a 100 Ω platinum RTD with $\alpha = 0.00385$ measures 138.5 Ω at 100 °C. Figure 2-3 shows a typical resistance-temperature curve for a 100 Ω platinum RTD.

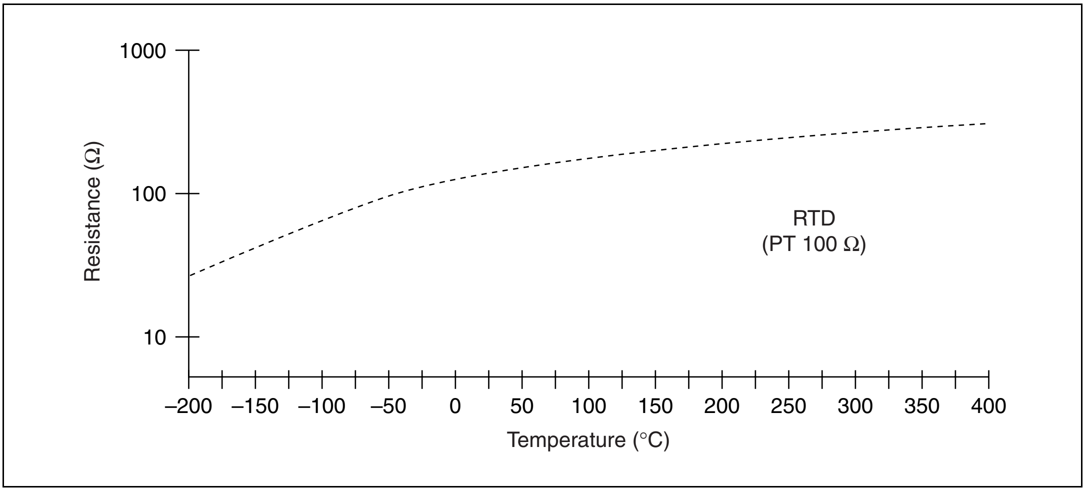

Figure 2-3. Resistance-Temperature Curve for a 100 Ω Platinum RTD

Although the resistance-temperature curve is relatively linear, converting measured resistance to temperature accurately requires curve fitting. The Callendar-Van Dusen equation is commonly used to approximate the RTD curve:

$$R_{RTD} = R_0[1 + A \times t + B \times t^2 + C \times (t - 100) \times t^3]$$

where R_{RTD} is the resistance of the RTD at temperature T_{RTD}; R_0 is the resistance of the RTD in Ω at 0 °C; A, B, and C are the Callendar-Van Dusen coefficients shown in Table 2-4; and T_{RTD} is the temperature in °C. For temperatures above 0 °C, coefficient C equals 0. Therefore, for temperatures above 0 °C, this equation reduces to a quadratic:

$$T_{RTD} = \frac{2\left(\frac{R_{RTD}}{R_0} - 1\right)}{A + \sqrt{A^2 + 4B\left(\frac{R_{RTD}}{R_0} - 1\right)}}$$

Most platinum RTD curves follow one of three standardized curves: the DIN 43760 standard ($\alpha = 0.00385$), the U.S. Industrial or American standard ($\alpha = 0.003911$), or the International Temperature Scale (ITS-90), which is used with wire-wound RTDs ($\alpha = 0.003925$). Table 2-4 lists the Callendar-Van Dusen coefficients for each of these three platinum RTD curves.

Table 2-4. Callendar-Van Dusen Coefficients Corresponding to Common RTDs

Standard	Temperature Coefficient α	A	B	C*
IEC751	0.00385055	3.9083×10^{-3}	-5.775×10^{-7}	-4.183×10^{-1}
DIN 43760	0.003850	3.9080×10^{-3}	-5.8019×10^{-7}	-4.2735×10^{-12}
American	0.003911	3.9692×10^{-3}	-5.8495×10^{-7}	-4.2325×10^{-12}
ITS-90	0.003925	3.9848×10^{-3}	-5.870×10^{-7}	-4.0000×10^{-12}

* For temperatures below 0 °C only; C = 0.0 for temperatures above 0 °C.

Note Software packages such as VirtualBench-Logger, NI 435*x* instrument driver, MAX Create New Channel Wizard, LabVIEW, and LabWindows/CVI include routines that perform these conversions for different types of RTDs based on the various commonly used standards.

Connecting the RTD

Because the RTD is a resistive device, you must pass current through the device and measure the resulting voltage. However, any resistance in the lead wires that connect the measurement system to the RTD adds errors to the readings. For example, consider a 2-wire RTD element connected to the NI 435*x* accessory that also supplies a constant current source I_{EX} to excite the RTD. As shown in Figure 2-4, the voltage drop across the lead resistance R_L, adds to the measured voltage.

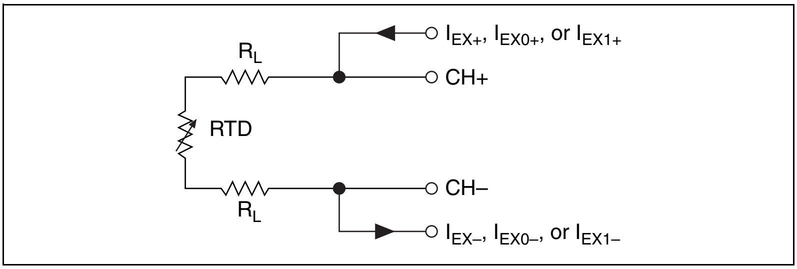

Figure 2-4. 2-Wire RTD Measurement

For example, a lead resistance R_L of 0.3 Ω in each wire adds a 0.6 Ω error to the resistance measurement. For a platinum RTD with $\alpha = 0.00385$, the resistance equals a 0.6 Ω /(0.385 Ω /°C) = 1.6 °C error.

If you are using lead lengths greater than 10 ft, you may need to compensate for this lead resistance in order to increase accuracy. The preferred RTD measurement method is to use a 4-wire RTD. One pair of wires carries the current through the RTD; the other pair senses the voltage across the RTD. Because only negligible current flows through the sensing wires, the lead resistance error of R_{L2} and R_{L3} is negligible. Figure 2-5 illustrates this configuration.

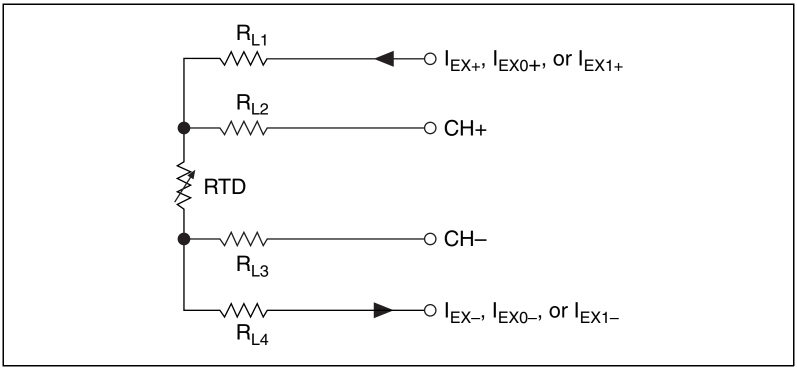

Figure 2-5. 4-Wire RTD Measurement

Alternatively, you can use a 3-wire RTD. Figure 2-6 shows a 3-wire RTD configuration with a current source. In this configuration, the resistance R_{L1} of only one lead adds error to the measurement.

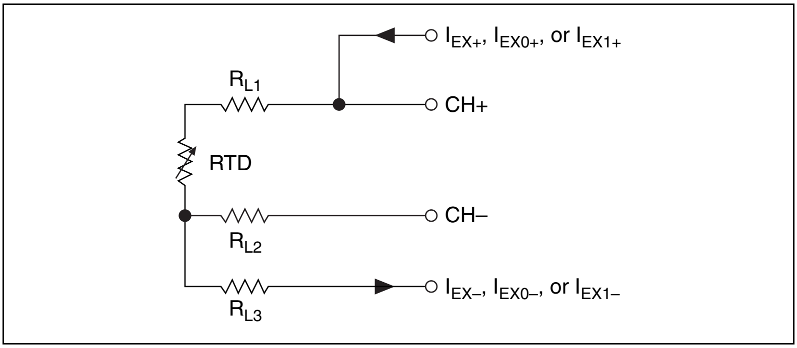

Figure 2-6. 3-Wire RTD Measurement

Another variation of the 3-wire RTD configuration is shown in Figure 2-7. In this configuration, the effects of the lead wire resistance cancel out as long as all three wires have the same lead resistance.

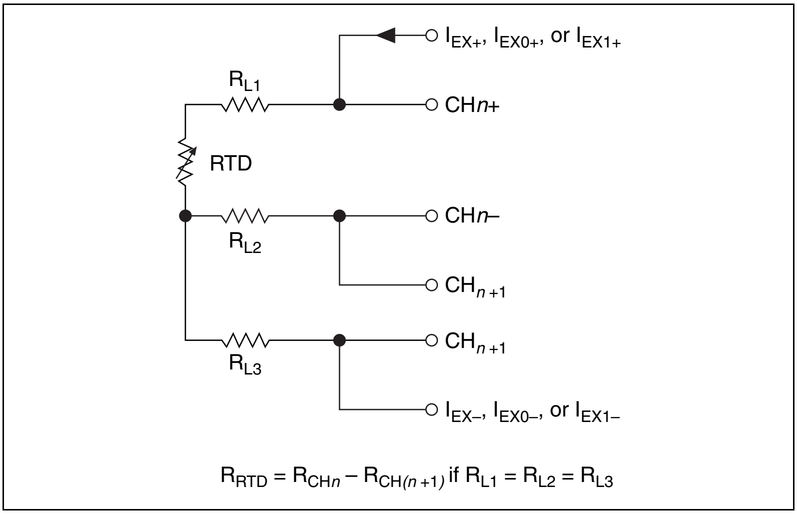

Figure 2-7. 3-Wire RTD Measurement and Lead Wire Resistance Compensation

Refer to Figure 2-10 for an example of how you can use different transducers connected to analog channels in the same measurement setup.

Note For best results, use the 1 mA current source when using the NI 4351 with RTDs with resistances below 1 kΩ . Refer to the `readme.htm` file found on the NI 435*x* CD for software issues regarding the 1 mA source. For resistances above 1 kΩ or with the NI 4350, use the 25 µA current source to avoid self-heating. Refer to the *Self-Heating* section for further details.

Introduction to Thermistors

A thermistor is a piece of semiconductor made from metal oxides, pressed into a small bead, disk, wafer, or other shape, which is sintered at high temperatures and finally coated with epoxy or glass. The resulting device exhibits an electrical resistance that varies with temperature.

There are two types of thermistors—negative temperature coefficient (NTC) thermistors and positive temperature coefficient (PTC) thermistors. An NTC thermistor is one whose resistance decreases with increasing temperature. A PTC thermistor is one whose resistance increases with increasing temperature. NTC thermistors are much more commonly used than PTC thermistors, especially for temperature measurement applications.

A main advantage of thermistors for temperature measurement is their high sensitivity. For example, a 2,252 Ω thermistor has a sensitivity of –100 Ω/°C at room temperature. Higher resistance thermistors can exhibit temperature coefficients of –10 kΩ/°C or more. In comparison, a 100 Ω platinum RTD has a sensitivity of only 0.4 Ω/°C. The small size of the thermistor bead also yields a fast response to temperature changes.

Another advantage of the thermistor is its relatively high resistance. Thermistors are available with base resistances (at 25 °C) ranging from hundreds to millions of ohms. This high resistance diminishes the effect of inherent resistances in the lead wires, which can cause significant errors with low resistance devices such as RTDs. For example, while RTD measurements typically require 4-wire or 3-wire connections to reduce errors caused by lead wire resistances, 2-wire connections to thermistors are usually adequate.

The major trade-off for the high resistance and sensitivity of the thermistor is its highly nonlinear output and relatively limited operating range. Depending on the type of thermistors, upper ranges are typically limited to around 300 °C. Figure 2-8 shows the resistance-temperature curve for a 5,000 Ω thermistor. The curve of a 100 Ω RTD also is shown for comparison.

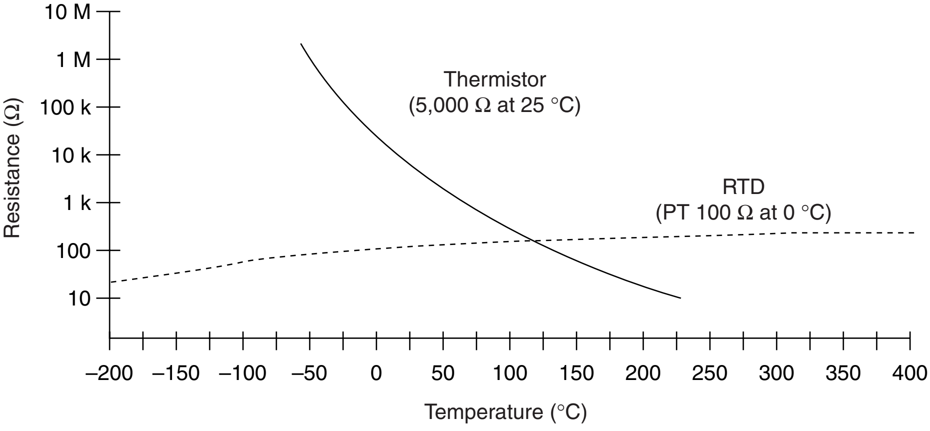

Figure 2-8. Resistance-Temperature Curve of a Thermistor

The thermistor has been used primarily for high-resolution measurements over limited temperature ranges. Continuous improvements in thermistor stability, accuracy, and availability of interchangeable thermistors have prompted increased usage of thermistors in all types of industries.

Resistance-Temperature Characteristic of Thermistors

The resistance-temperature behavior of thermistors is highly dependent upon the manufacturing process. Therefore, thermistor manufacturers have not standardized thermistor curves to the extent that thermocouple or RTD curves are standardized.

Typically, thermistor manufacturers supply the resistance-versus-temperature curves or tables for their particular devices. The thermistor curve, however, can be approximated relatively accurately with the Steinhart-Hart equation:

$$T(\mathrm{K}) = \frac{1}{a + b \times \ln(R_t) + c \times \ln^3(R_t)}$$

Where $T(\mathrm{K})$ is the temperature in kelvin, equal to $T(°\mathrm{C}) + 273.15$, and R_t is the resistance of the thermistor. The coefficients a, b, and c can be provided by the thermistor manufacturer, or calculated from the resistance-versus-temperature curve.

Software packages such as LabVIEW and LabWindows/CVI include routines that perform these conversions for some types of thermistors. You also can modify these conversion routines for the particular type of thermistor.

Connecting the Thermistor

Because the thermistor is a resistive device, you must pass a current through the thermistor to produce a voltage that can be measured by the NI 435*x*. The high resistance and high sensitivity of the thermistor simplify the necessary measurement circuitry and signal conditioning. Special 3-wire or 4-wire connections are not necessary. As shown in Figure 2-9, the measured voltage V_t is equal to ($R_t \times I_{EX}$).

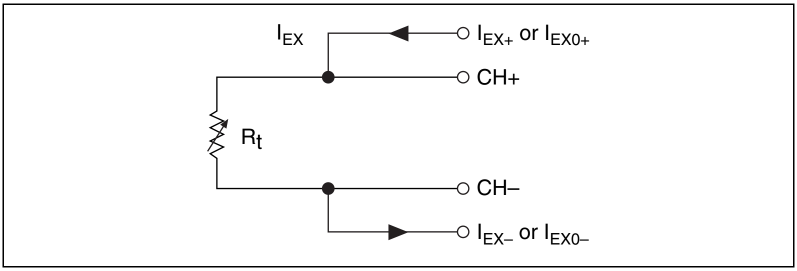

Figure 2-9. Thermistor Measurement

Refer to Figure 2-10 for an example of how you can use different transducers connected to analog channels in the same measurement setup.

Note Use the 25 µA current source for thermistors above 1 kΩ to avoid self-heating. Refer to the *Self-Heating* section for further details.

Connecting the Resistor

You can use signal connection techniques, described in the *Connecting the RTD* section and the *Connecting the Thermistor* section, for any resistor as well.

The NI 435*x* accessories—the TBX-68T, CB-68T, and TBX-68 for the NI 435*x* for USB, PXI, and PCI—are designed to be used with RTDs, thermistors, and resistors. Consult the accessory installation guide for instructions on how to connect the resistors. Figures 2-10 and 2-11 show examples of how to use different transducers connected to analog channels in the same measurement setup.

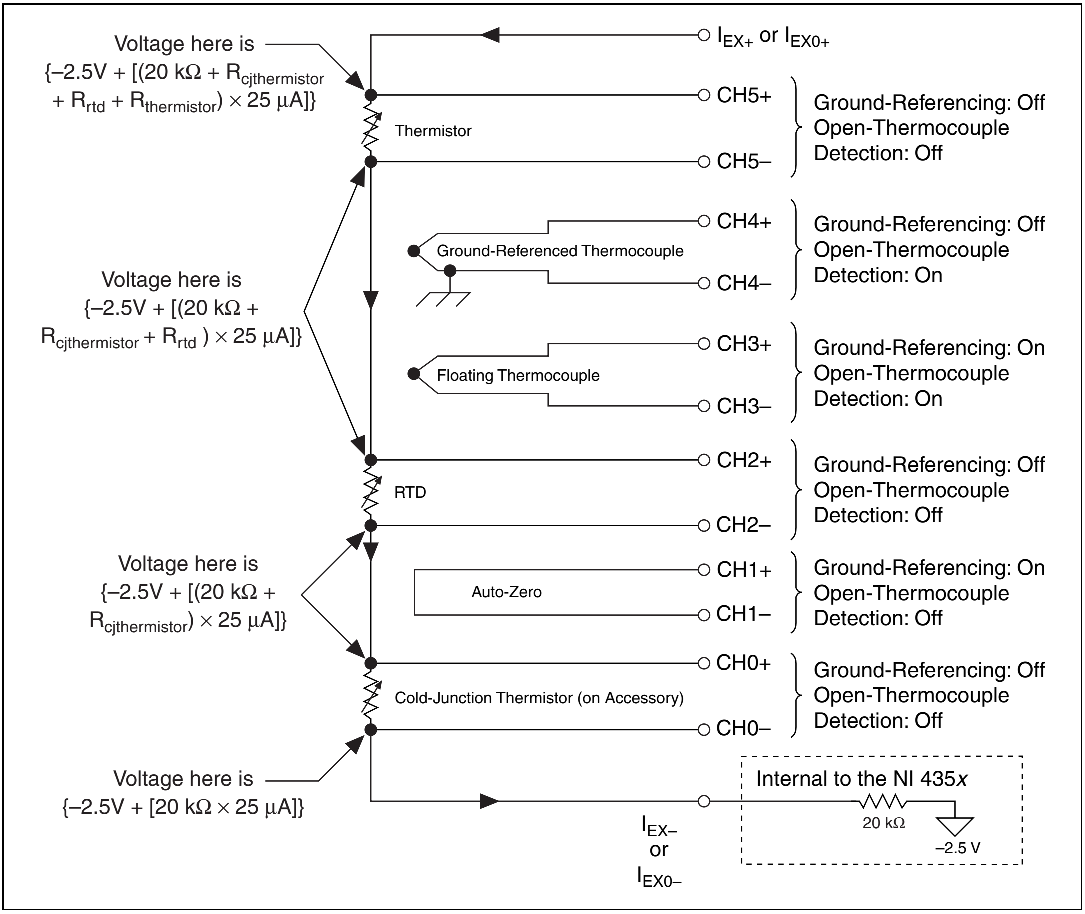

Figure 2-10. Multiple Transducer Connections to Analog Channels in One Measurement Setup, Channels 0–5

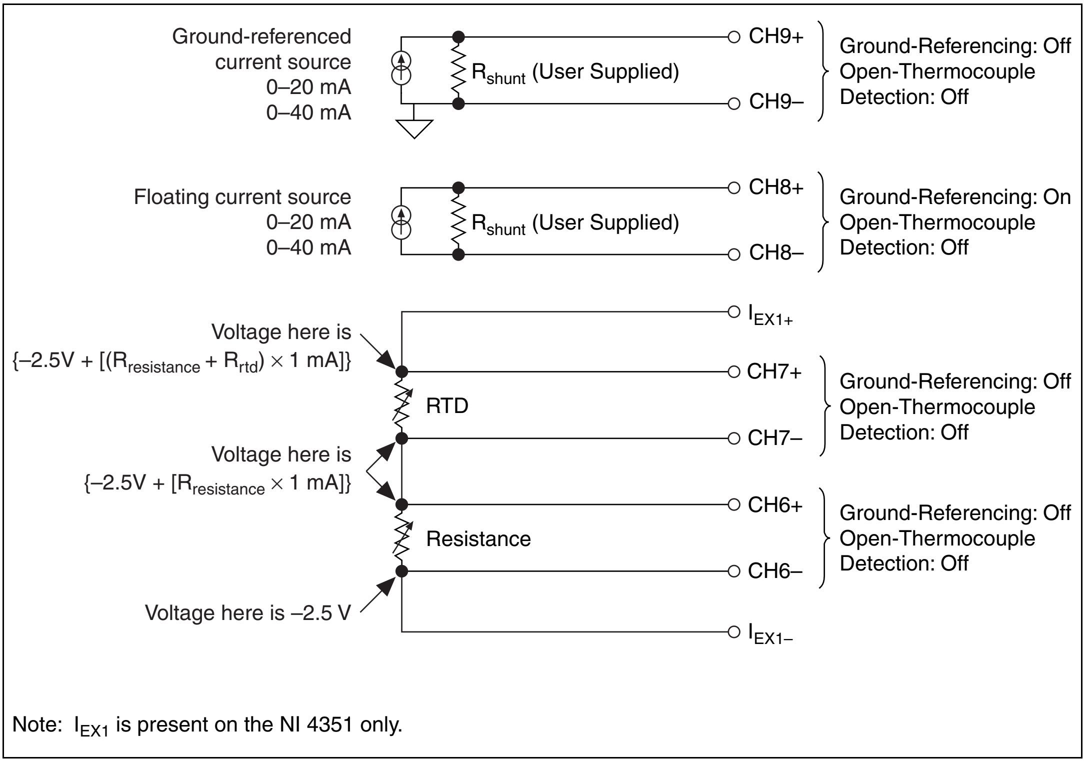

Figure 2-11. Multiple Transducer Connections to Analog Channels in One Measurement Setup, Channels 6–9

The NI 435*x* analog inputs are protected against damage from voltages within ±42 VDC in all ranges when powered on and ±17 VDC when powered off.

Caution *Never* apply voltages above these levels to the inputs. To prevent possible safety hazards, the maximum voltage between any of the analog inputs and the computer ground should never exceed ±42 VDC when the NI 435*x* is powered on and ±17 VDC when the NI 435*x* is powered off.

Input Ranges

The NI 435*x* has six ranges for resistance measurements. These ranges are 25 kΩ, 50 kΩ, 100 kΩ, 150 kΩ, 300 kΩ, and 600 kΩ with the 25 µA current source. These ranges correspond to the six input ranges available for measuring DC voltages developed across resistors. These ranges are ±625 mV, ±1.25 V, ±2.5 V, ±3.75 V, ±7.5 V, and ±15 V. The NI 4351 for

PXI and PCI has six additional ranges of 625 Ω, 1.25 kΩ, 2.5 kΩ, 3.75 kΩ, 7.5 kΩ, and 15 kΩ with the 1 mA current source.

To determine the most suitable input range for the application, estimate the voltage developed across the resistor by following the procedure outlined in Figures 2-10 and 2-11. Estimate the common-mode voltage at the inputs, and verify that the range you select can handle that common mode voltage. Choose the lowest range in the 4-wire ohms mode when you are measuring RTDs and thermistors, for best results.

The NI 435*x* can measure resistances to its specified accuracy as long as the voltage across the resistors is within the selected input range specified above. To get the best resolution, noise rejection, and accuracy, choose the smallest range in which the signals can be accommodated. Make sure that each signal input to CH+ and CH– is within the input common-mode limits of this input range. The input common-mode limits are ±2.5 V and ±15 V, for the lower three and higher three input ranges, respectively.

For resistance higher than 25 kΩ, a settling time of over 1 s may be required when changing channels, to achieve the specified accuracy.

Optimizing Measurements

In addition to the potential problems discussed in the sections on connecting the RTDs and thermistors, also consider other problems associated with AC noise effects, thermal EMF, and other errors as discussed in the following sections.

Auto-Zero

Auto-zero is a method that instruments use to remove any offset errors in the measurement. Analog channel 1 (CH1) on the PSH32-TC6, CB-27T, TC-2190, TBX-68T, and CB-68T is dedicated for auto-zero. CH1+ is connected to CH1– on these accessories. You can measure the voltage offset on this auto-zero channel and subtract it from the voltage measurements on other channels. This way, you can compensate for any residual offset error the NI 435*x* may have. This is especially useful when the NI 435*x* is operating at an ambient temperature other than that of calibration (23 °C typical). Use the 4-wire mode in LabVIEW while reading the offset for resistance measurements.

Programmable Ground-Referencing

Always switch off ground-referencing on the channel connected to a resistor excited by the current source. The current source return terminals, I_{EX-}, I_{EX0-}, and I_{EX1-}, are tied to –2.5 V through internal circuits. This –2.5 V causes any resistor excited by the current source to be ground-referenced. Otherwise, the leakage current flowing into the resistor can cause erroneous measurements for all channels that use the current source.

Programmable Open-Thermocouple Detection

Always switch off open-thermocouple detection on the channel connected to a resistor. Otherwise, the leakage current flowing into the resistor can cause erroneous measurements for all channels that use the current source.

Connecting to External Circuits

Refer to Figures 2-10 and 2-11 for examples of how different transducers connect to analog channels in the same measurement setup. To measure the value of a resistor accurately, make sure the resistor is not electrically connected to any other circuits. Erroneous or misleading readings can result if the resistor you are measuring is electrically connected to external circuits that supply voltages or currents or is connected to external circuits that change the effective resistance of that resistor.

2-Wire, 3-Wire, and 4-Wire Measurements

The discussion in the *Connecting the RTD* section on whether to use 2-wire, 3-wire, or 4-wire, applies to any resistance measurement. Choose the appropriate measurement technique for the application as shown in Table 2-5.

Table 2-5. Guidelines for Resistance Measurement

Resistance Being Measured (Ω)	Measurement Technique
R ≤ 1 kΩ	4-wire
1 kΩ < R ≤ 10 kΩ	4-wire or 3-wire
R > 10 kΩ	4-wire, 3-wire, or 2-wire

Self-Heating

The current source on the NI 435*x* is designed so that any error resulting from self-heating is negligible in most cases.

When current is passed through an RTD or a thermistor (both are resistive devices), the power dissipated is equal to I^2R, which heats the resistive devices. This phenomena is called *self-heating* and is typically specified by manufacturers in the form of the dissipation constant. The dissipation constant is the power required to heat the thermistor by 1 °C from ambient temperature, and it is usually represented in units of mW/°C. The dissipation constant depends significantly on how easily heat is transferred away from the thermistor, so the dissipation constant may be specified for different media—in still air, water, or oil bath.

Thermistors, with their small size and high resistance, are particularly prone to these self-heating errors. Typical dissipation constants range anywhere from less than 0.5 mW/°C for still air to 10 mW/°C or higher for a thermistor immersed in water. A 5,000 Ω thermistor powered by a 25 µA excitation current dissipates as follows:

$$I^2R = (25\ \mu\text{A})^2 \times 5{,}000\ \Omega = 3.1\ \mu\text{W}$$

If this thermistor has a dissipation constant of 10 mW/°C, the thermistor self-heats by only 0.003 °C. Thus, the small value of the current source helps prevent any appreciable error due to self-heating.

RTDs are relatively immune to the problem of self-heating because their resistance is relatively small, such as 100 Ω at 0 °C. Also, the amount of self-heating depends significantly on the medium in which the RTD is immersed. An RTD can self-heat up to 100 times higher in still air than in moving water. The self-heating in RTDs due to the built-in 25 µA is negligible. When using 1 mA excitation current, a 100 Ω RTD dissipates as follows:

$$I^2R = (1\ \text{mA})^2 \times 100\ \Omega = 0.1\ \text{mW}$$

If this RTD has a dissipation constant of 5 mW/°C, the RTD self-heats by 0.02 °C.

AC Noise Effects

The NI 435*x* rejects AC noise as specified in NMR in Appendix A, *Specifications*. However, if the amplitudes of the AC noise are large compared to the DC signal, or if the peak value (AC plus DC) of the measured signal is outside the input range, the NI 435*x* may exhibit additional errors. To minimize these errors, keep the signal source, the NI 435*x*, and its accessory away from strong AC magnetic sources and minimize the area of the loop formed by the wires connecting the signal source with the accessory. Choosing the notch filter frequency of 10 Hz provides the best AC noise rejection. If the peak value of the measured voltage is likely to exceed the selected input range, select the next higher input range.

Thermal EMF

Thermoelectric potentials or thermal EMFs are voltages generated at the junctions of dissimilar metals and are functions of temperature. Thermal EMFs in the source generating the signal can introduce errors in measurements that change with variations in temperature.

To minimize thermal EMFs, use copper wires to connect the signal to the NI 435*x* accessory. Avoid using dissimilar metal wires in connections. Also, keep out temperature gradients in the space enclosing the signal source, the NI 435*x*, and its accessories.

Using the Current Source

The NI 435*x* features a precision current source, which supplies 25 µA and provides excitation to a total maximum resistance of 600 kΩ. The NI 4351 has an additional precision current source, which supplies 1 mA and provides excitation to a total maximum resistance of 15 kΩ.

These resistances can be in the form of RTDs, thermistors, or any other resistor. The calibrated value of the current source is stored on-board, and NI-DAQ uses this precise value in its computations. Refer to the *Measuring Temperature with RTDs and Thermistors and Measuring Resistance* section for details on how to use this current source.

Using Digital Inputs and Outputs

The NI 435*x* features TTL-compatible digital lines. These lines can be individually configured either as inputs or as outputs. When the NI 435*x* powers on, these digital lines are configured as high-impedance inputs.

You can use the DIO lines as an interface to control processes; control events such as turning on and off heaters, relays, motors, or lights; generate patterns for testing; and communicate with peripheral equipment. If the current and voltage specifications of the DIO lines are not appropriate for the requirements, you can use external signal conditioning such as electromechanical relay, solid-state relay, opto-coupler, and so on.

You can use the digital input lines to trigger analog acquisitions. To trigger analog acquisitions with the LabVIEW or NI 435*x* instrument driver, set up the analog acquisition configuration, then poll the digital input line for the trigger condition and, upon getting the trigger, start the analog acquisition.

Connecting the Digital Input and Output

All NI 435*x* accessories are designed to be used for DIO. Refer to the accessory installation guide for instructions on how to connect the DIO lines. Figure 2-12 shows examples of how to connect DIO for various applications such as controlling an LED; monitoring a TTL-compatible or CMOS-compatible signal; monitoring a low-voltage switch; and monitoring a low-voltage transistor.

For the NI 435*x* for USB, PXI, and PCI, you can use the TBX-68T (revision C or later) and the CB-68T to connect to digital signal conditioning accessories with optocouplers, solid-state relays, and electromechanical relays, such as the SC-2061, SC-2062, SC-2063, SSR Series, and ER Series.

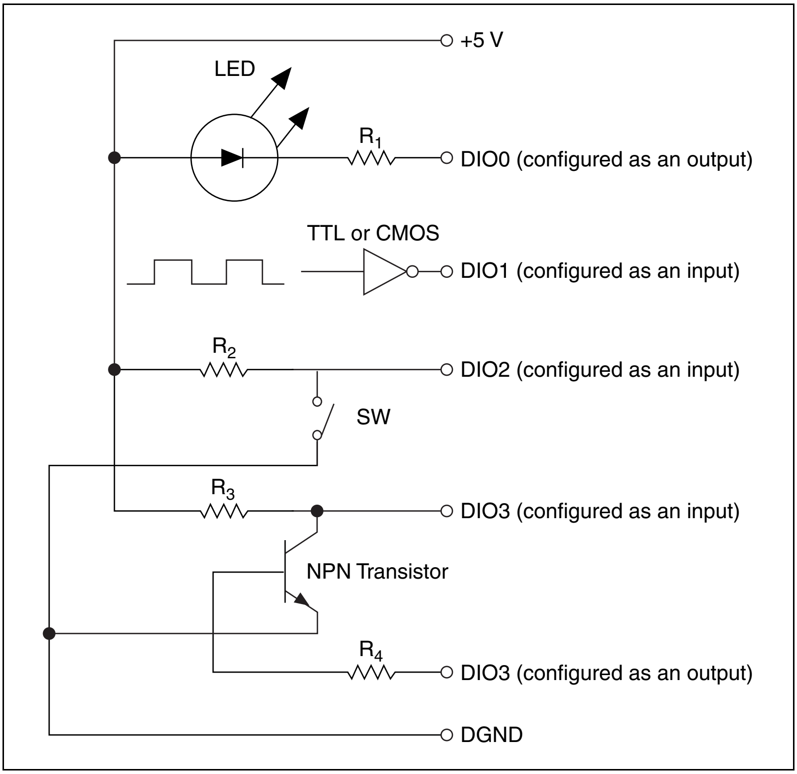

Figure 2-12. Examples of DIO Applications

Caution To prevent possible safety hazards, the voltage applied to the digital I/O lines should *never* be outside –0.5 V and +5.5 V, with respect to DGND.

The DIO lines of the NI 435*x* are protected against damage from voltages within –0.5 and +5.5 V with respect to digital ground (DGND). Never apply voltages above these levels to these signals.

Note If the number of digital input lines is not adequate for the application, you can use the analog input channels to measure the voltage of the digital signal you want to measure. Then you can determine the logic level based on the thresholds of the logic family of the digital signal you are monitoring. Table 2-6 shows the thresholds of CMOS and TTL logic families using analog inputs as digital inputs.

Table 2-6. Logic Family Thresholds

Logic Family	Low	High
CMOS	<0.8 V	>2.0 V
TTL	<0.8 V	>2.0 V
Note: Check the logic family data sheets for any variations.		

A

Specifications

This appendix lists the specifications of the NI 4350 and NI 4351. These specifications are for a 15 to 35 °C ambient temperature range for one year unless otherwise specified. All specifications are relative to calibration standards and require a 30 minute warm-up period. Specifications do not include transducer errors. Temperature coefficient is applicable for 0 °C to 15 °C and 35 °C to 55 °C. For thermocouples, add the accessory error in °C only if the accessory (TC-2190, PSH32-TC6, CB-27T, TBX-68T, CB-68T) is in the 0 °C to 15 °C and 35 °C to 55 °C temperature range.

Accuracy Specifications

Thermocouple Accuracy[1]

Thermocouple Type	°C	Error (°C) 15 °C–35 °C, 1 Year — Filter Setting: 10 Hz	50 Hz	60 Hz	0 °C–15 °C, 35 °C–55 °C: Temperature Coefficient (°C/°C*)	Accessory Error (°C**)
J	–100	0.53	0.61	0.74	0.02	0.25
	0	0.42	0.49	0.59		
	760	0.42	0.47	0.55		
K	–100	0.60	0.72	0.89	0.03	0.27
	0	0.45	0.54	0.67		
	1,000	0.60	0.69	0.81		
	1,372	0.74	0.84	0.99		

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[1] Thermocouple measurement specifications include cold-junction compensation error (with sensor between 15 °C and 35 °C), isothermal accuracy, and system noise. The specifications assume that the 0.625 V range is used and that ground-referencing and open-thermocouple detection are enabled for a floating thermocouple. Specifications improve with ground-referencing enabled and open-thermocouple detection disabled for a floating thermocouple. The specifications also assume that the cold-junction sensor is between 15 °C and 35 °C.

		Error (°C) 15 °C–35 °C, 1 Year			**0 °C–15 °C, 35 °C–55 °C**	
		Filter Setting				
Thermocouple Type	**°C**	**10 Hz**	**50 Hz**	**60 Hz**	**Temperature Coefficient (°C/°C*)**	**Accessory Error (°C**)**
N	–100	0.68	0.84	1.08	0.03	0.26
	0	0.54	0.67	0.86		
	400	0.42	0.51	0.65		
	1,300	0.57	0.66	0.80		
E	–100	0.55	0.62	0.74	0.02	0.28
	0	0.41	0.46	0.55		
	500	0.35	0.40	0.46		
	1,000	0.46	0.50	0.57		
T	–150	0.81	0.96	1.17	0.03	0.36
	0	0.46	0.55	0.68		
	400	0.33	0.39	0.47		
R	250	0.82	1.16	1.65	0.06	0.12
	1,000	0.72	0.99	1.37		
	1,767	0.91	1.19	1.60		
S	250	0.91	1.28	1.83	0.07	0.13
	1,000	0.77	1.05	1.47		
	1,767	0.96	1.27	1.72		
B	600	1.08	1.64	2.47	0.11	0.00
	1,000	0.76	1.14	1.69		
	1,820	0.74	1.05	1.50		

* Add when thermocouple accessory and NI 435*x* is outside 15 °C–35 °C temperature range.

** Add when thermocouple accessory is outside 15 °C–35 °C temperature range.

RTD Accuracy (with I_{EX} or I_{EX0})[1]

		Error (°C) 15 °C–35 °C, 1 Year			0 °C–15 °C, 35 °C–55 °C
		Filter Setting			Temperature Coefficient (°C/°C)
RTD	**°C**	**10 Hz**	**50 Hz**	**60 Hz**	
Pt 100 Ω	–200	1.00	1.33	1.81	0.01
	0	1.14	1.49	2.00	
	100	1.22	1.58	2.10	
	300	1.38	1.76	2.32	
	600	1.66	2.08	2.69	

RTD Accuracy (with I_{EX1})[2]

		Error (°C) 15 °C–35 °C, 1 Year			0 °C–15 °C, 35 °C–55 °C
		Filter Setting			Temperature Coefficient (°C/°C)
RTD	**°C**	**10 Hz**	**50 Hz**	**60 Hz**	
Pt 100 Ω	–200	0.05	0.06	0.07	0.01
	0	0.12	0.13	0.14	
	100	0.16	0.17	0.18	
	300	0.23	0.24	0.26	
	600	0.36	0.37	0.39	

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[1] RTD specifications assume that the 25 kΩ (25 μA current source) range is used and worst case common-mode voltage for this range is present. Specifications improve if actual common-mode voltage is less than worst case. Specifications improve for a 1,000 Ω RTD.

[2] RTD specifications assume that the 625 Ω range (1 mA current source) is used and worst case common-mode voltage for this range is present. Specifications improve if actual common-mode voltage is less than worst case.

Thermistor Accuracy (with I_{EX} or I_{EX0})[1]

		Accuracy (°C) 15 °C–35 °C, 1 Year, Filter Setting: 10 Hz, 50 Hz, 60 Hz	**Temperature Coefficient 0 °C–15 °C, 35 °C–55 °C**
Thermistor	**°C**	**°C**	**°C/°C**
5,000 Ω	0–50	0.03	0.001

DC Voltage Accuracy[2]

	% of Reading 15 °C–35 °C			**Add µV (with Auto-Zero) 15 °C–35 °C**			**Add µV (without Auto-Zero) 15 °C–35 °C**			**Temperature Coefficient 0–15 °C, 35 °C–55 °C**	
				Filter Setting			**Filter Setting**				
Range (Volts)	**24 Hour**	**90 Day**	**1 Year**	**10 Hz**	**50 Hz**	**60 Hz**	**10 Hz**	**50 Hz**	**60 Hz**	**% Reading/ °C**	**µV/°C**
15	0.0146	0.0175	0.0205	28	117	141	130	193	210	0.0009	5
7.5	0.0152	0.0181	0.0211	21	71	106	125	160	185	0.0009	5
3.75	0.0164	0.0193	0.0223	14	30	42	120	131	140	0.0010	5
2.5	0.0066	0.0095	0.0125	5	17	24	24	32	37	0.0004	1
1.25	0.0072	0.0101	0.0131	3	12	18	22	29	33	0.0004	1
0.625	0.0084	0.0113	0.0143	2	6	11	22	24	28	0.0005	1

Note To learn how to calculate DC voltage accuracy, and if you have a thermistor other than 5,000 K, refer to `ni.com\support` and then click **KnowledgeBase** under *Option 3*. Enter `1W3E9CHE` in the search field to access the entry called *How to Calculate the Accuracy of a Specific Resistance Sensor.*

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[1] Thermistor accuracy is valid for all filter settings. Specifications assume that the 25 kΩ range is used and worst case common-mode voltage for this range is present. Specifications improve if actual common-mode voltage is less than worst case.

[2] Voltage specifications do not include errors resulting from common-mode voltages. Calculate additional errors because of common-mode voltages as: common-mode voltage/$10^{(\text{CMR specification in db/20})}$.

Resistance Accuracy (with I_{EX} or I_{EX0})[1]

Range (W)	% of Reading 15–35 °C			Add Ω (with Auto-Zero) 15–35 °C			Add Ω (without Auto-Zero) 15–35 °C			Temperature Coefficient 0–15 °C, 35–55 °C
				Filter Setting			Filter Setting			
	24 Hour	90 Day	1 Year	10 Hz	50 Hz	60 Hz	10 Hz	50 Hz	60 Hz	%Reading/°C
600,000	0.0435	0.0464	0.0494	20.11	23.64	24.63	24.17	26.67	27.37	0.0013
300,000	0.0441	0.0470	0.0500	19.82	21.80	23.22	23.97	25.37	26.37	0.0013
150,000	0.0453	0.0482	0.0512	19.54	20.16	20.67	23.77	24.21	24.57	0.0013
100,000	0.0355	0.0384	0.0414	0.51	1.00	1.28	1.26	1.60	1.80	0.0013
50,000	0.0361	0.0390	0.0420	0.45	0.80	1.02	1.21	1.46	1.62	0.0013
25,000	0.0373	0.0402	0.0432	0.41	0.54	0.74	1.18	1.28	1.42	0.0013

Resistance Accuracy (with I_{EX1})[2]

Range (W)	% of Reading 15–35 °C			Add Ω (with Auto-Zero) 15–35 °C			Add Ω (without Auto-Zero) 15–35 °C			Temperature Coefficient 0–15 °C, 35–55 °C
				Filter Setting			Filter Setting			
	24 Hour	90 Day	1 Year	10 Hz	50 Hz	60 Hz	10 Hz	50 Hz	60 Hz	%Reading/°C
15,000	0.0320	0.0349	0.0379	1.53	1.62	1.64	1.63	1.69	1.71	0.0013
7,500	0.0326	0.0355	0.0385	1.52	1.57	1.61	1.63	1.66	1.69	0.0013
3,750	0.0338	0.0367	0.0397	1.51	1.53	1.54	1.62	1.63	1.64	0.0013
2,500	0.0240	0.0269	0.0299	0.03	0.04	0.05	0.05	0.06	0.06	0.0013
1,250	0.0246	0.0275	0.0305	0.03	0.04	0.04	0.05	0.05	0.06	0.0013
625	0.0258	0.0287	0.0317	0.02	0.02	0.02	0.04	0.04	0.04	0.0013

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[1] Resistance specifications assume worst case common-mode voltage for the given range. Specifications improve if actual common-mode voltage is less than worst case. Measurement accuracy is affected by source impedance. Resistances >25 kΩ may require 1 s setting time.

[2] Resistance specifications assume worst case common-mode voltage for the given range. Specifications improve if actual common-mode voltage is less than worst case. Measurement accuracy is affected by source impedance.

Accuracy Calculation Examples

The following are accuracy calculation examples:

- Measurement of 760 °C using J-type thermocouple at 28 °C ambient temperature; filter setting of 10 Hz:

  accuracy is 0.42 °C
- Measurement of 760 °C using J-type thermocouple with NI 4350 at 38 °C and accessory (cold-junction sensor) at 23 °C; filter setting of 10 Hz:

  accuracy is 0.48 °C as a result of
  [0.42 °C + (38 °C – 35 °C) × 0.02]
- Measurement of 760 °C using J-type thermocouple with NI 4350 and accessory (cold-junction sensor) at 38 °C; filter setting of 10 Hz:

  accuracy is 0.73 °C as a result of
  [0.42 °C + (38 °C – 35 °C) × 0.02 + 0.25 °C]
- Measurement of 1 V using 1.25 V range, filter setting of 60 Hz at 28 °C ambient temperature after 90 days of calibration with auto-zero; at 0 V common-mode voltage:

  accuracy is 119 µV as a result of
  [1 V × 0.0101% +18 µV]
- Measurement of 1 V using 1.25 V range, filter setting of 60 Hz at 38 °C ambient temperature after 90 days of calibration, with auto-zero; at 0.5 V common-mode voltage:

  accuracy is 139 µV, as a result of
  [1 V × 0.0101% +18 µV + (38 °C – 35 °C) ×
  {1 V × 0.0004%/°C + 1 µV/°C}+ ($0.5V/10^{100/20}$)]

Analog Input

Input Characteristics

Number of channels	16 differential or 14 thermocouple
Digits	5 1/2
Type of ADC	Sigma-delta
ADC resolution	24 bits, no missing codes
Calibration cycle	1 year

Input coupling .... DC

Over-voltage protection

(CH<0..8/15>, $I_{EX\pm}$,
$I_{EX0\pm}$, $I_{EX1\pm}$) .... ±42 V powered on;
±17 V powered off

Data transfers .... Interrupts, programmed I/O

Warm-up time .... 30 minutes

Amplifier Characteristics

Input impedance

Normal powered on .... >1 GΩ in parallel with 0.39 µF

Powered off.................................... 10 kΩ

Overload... 10 kΩ

Open-thermocouple detection .... 10 MΩ between CH+ and +2.5 V
(software-selectable)

Ground-referencing .... 10 MΩ between CH– and ground
(software-selectable)

Input bias current .... <500 pA

CMR (DC, 50 Hz, 60 Hz, 400 Hz)

Range ≥2.5 V .... 80 dB

Range <2.5 V .... 100 dB

NMR (50 Hz, 60 Hz, 400 Hz) .... >100 dB

Dynamic Characteristics

Bandwidth .... 20 Hz

Step response (full-scale step)

Accuracy	Time(s)
±0.1%	0.3
±0.01%	0.5
±0.0015%	2.4

Accuracy	Time(s)
±0.001%	3
±0.0004%	7

Excitation

Note The exact value of the excitation current is stored on the hardware. NI-DAQ uses this value when taking resistance measurements.

Number of channels 2

Parameter	I_{EX} or I_{EX0}	I_{EX1}
Level	25 µA	1 mA[1]
Maximum Load Resistance	600 kΩ	15 kΩ
Temperature Coefficient	±15 ppm/°C	±15 ppm/°C

[1] The 1 mA excitation level is only available on the NI 4351.

Digital I/O and Alarm Outputs

Number of lines 8

Compatibility ....TTL

DIO<0..3/7>

Level	Minimum	Maximum
Input low voltage	0.0 V	0.8 V
Input high voltage	2.0 V	5.0 V (V_{CC})
Input low current (V_{in} = 5 V)	—	–10 µA
Input high current (V_{in} = 5 V)	—	10 µA)
Output low voltage (I_{out} = 8 mA)	—	0.4 V
Output high voltage (I_{out} = 8 mA)	3.8 V	—

Power-on state	Tristate
Data transfers	Programmed I/O

Bus Interface

Type	Slave (Plug and Play)

Power Requirements

USB	High-power, USB-powered peripheral (500 mA)
PXI	480 mA at +5 V
PCI	480 mA at +5 V
Power available at I/O connector	+4.6 V to +5.2 V, 1 A (PXI, PCI) +4.6 V to +5.2 V, 50 mA (USB)

Physical

Dimensions	
USB	14.6 × 21.3 × 3.8 cm (5.8 × 8.4 × 1.5 in.)
PXI	16 × 10 cm (6.3 × 3.9 in.)
PCI	PCI (half size)
I/O connector	68-pin male, shielded and latched

Maximum Working Voltage

Maximum working voltage refers to the signal voltage plus the common-mode voltage.

Range >2.5 V	Each input should remain within ±15 V of ground
Range ≤2.5 V	Each input should remain within ±2.5 V of ground

Environmental

Operating temperature	0 to 55 °C
Storage temperature	–20 to 70 °C
Humidity	Up to 80% RH, noncondensing
Maximum altitude	2,000 m
Installation Category	I
Pollution Degree (indoor use only)	2

Safety

♦ PCI/PXI Only

The NI PCI/PXI-4051 meets the requirements of the following standards for safety and electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 3111-1, UL 61010B-1
- CAN/CSA C22.2 No. 1010.1

Note For UL and other safety certifications, refer to the product label, or visit `ni.com/hardref.nsf`, search by model number or product line, and click the appropriate link in the Certification column.

Electromagnetic Compatibility

Emissions	EN 55011 Class A at 10 m FCC Part 15A above 1 GHz
Immunity	EN 61326:1997 + A2:2001, Table 1
EMC/EMI	CE, C-Tick, and FCC Part 15 (Class A) Compliant

Note For EMC compliance, you *must* operate this device with shielded cabling.

CE Compliance

The NI 435*x* devices meet the essential requirements of applicable European Directives, as amended for CE marking, as follows:

Low-Voltage Directive (safety) 73/23/EEC

Electromagnetic Compatibility
Directive (EMC) 89/336/EEC

Note Refer to the Declaration of Conformity (DoC) for this product for any additional regulatory compliance information. To obtain the DoC for this product, visit `ni.com/hardref.nsf`, search by model number or product line, and click the appropriate link in the Certification column.

B

Signal Connections

This section explains the signal correlation between the NI 435*x* and the accessories you might use with it.

Table B-1 shows how the screw terminals on the TBX-68 connector block, and the SH6868 cable and the R6868 cables correspond to the signal names on the NI 435*x* (USB, PXI, PCI).

Table B-1. Using the NI 435*x* (USB, PXI, PCI) with the TBX-68

NI 435*x* (USB, PXI, PCI) Signal Name	TBX-68 Screw Terminal
CH0+	68
CH0–	34
CH1+	33
CH1–	66
CH2+	65
CH2–	31
CH3+	30
CH3–	63
CH4+	62
CH4–	29
CH5+	28
CH5–	61
CH6+	60

Table B-1. Using the NI 435*x* (USB, PXI, PCI) with the TBX-68 (Continued)

NI 435*x* (USB, PXI, PCI) Signal Name	**TBX-68 Screw Terminal**
CH6–	26
CH7+	25
CH7–	58
CH8+	57
CH8–	23
CH9+	22
CH9–	55
CH10+	54
CH10–	21
CH11+	19
CH11–	53
CH12+	52
CH12–	18
CH13+	17
CH13–	50
CH14+	49
CH14–	15
CH15+	13
CH15–	46
I_{EX+}, I_{EX0+} (NI 4351)	12
I_{EX-}, I_{EX0-} (NI 4351)	45

Table B-1. Using the NI 435*x* (USB, PXI, PCI) with the TBX-68 (Continued)

NI 435*x* (USB, PXI, PCI) Signal Name	**TBX-68 Screw Terminal**
I_{EX1+} (NI 4351 only)	44[1]
I_{EX1-} (NI 4351 only)	10[1]
DIO0	7
DIO1	6
DIO2	5
DIO3	4
DIO4	37
DIO5	3
DIO6	2
DIO7	1
+5V	8[2]
DGND	35, 36, 38, 39, 40, 41, 42
AGND	9, 10, 11, 14, 16, 20, 24, 27, 32, 43, 44, 47, 48, 51, 56, 59, 64, 67

[1] Screw terminals 10 and 44 are AGND on the NI 4350 only and are not labeled AGND on revision C or later of the TBX-68T.

[2] The current available may be limited to less than 50 mA (typical) when using the NI 4350 (USB).

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Glossary

Symbol	Prefix	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}
G	giga	10^{9}
T	tera	10^{12}

Numbers/Symbols

°	degree
–	negative of, or minus
Ω	ohm
/	per
%	percent
±	plus or minus
+	positive of, or plus
+5V	+5 V output signal

A

A	amperes
AC	alternating current

AC coupled	allowing the transmission of AC signals while blocking DC signals
ADC	analog-to-digital converter—an electronic device that converts an analog voltage to a digital number
AGND	analog ground signal
ANSI	American National Standards Institute
AT bus	*See* bus.
attenuation	decreasing the amplitude of a signal
auto-zeroing	the process of removing an offset error from a measurement
AWG	American Wire Gauge

B

b	bit—one binary digit, either 0 or 1
B	byte—eight related bits of data, an eight-bit binary number. Also used to denote the amount of memory required to store one byte of data.
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 signals that interconnect individual circuitry in a computer. Typically, a bus is the expansion vehicle to which I/O or other instruments are connected. Examples of PC buses are the AT bus (also known as the ISA bus) and the PCI bus.

C

C	Celsius
CH	channel

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.
clock	hardware component that controls timing for reading from or writing to groups
CMOS	complimentary metal oxide semiconductor
CMR	common-mode rejection
CompactPCI	refers to the core specification defined by the PCI Industrial Computer Manufacturer's Group (PICMG)
coupling	the manner in which a signal is connected from one location to another
CPU	central processing unit

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: $\text{dB} = 20 \times \log_{10}(V_1/V_2)$ for signals in volts
DC	direct current
DC coupled	allowing the transmission of both AC and DC signals
device	a plug-in data acquisition product, card, or pad that can contain multiple channels and conversion devices. Plug-in products 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.
DGND	digital ground signal
DIO	digital input and output

drivers	software that controls a specific hardware device such as a DAQ device or a GPIB interface
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
EMF	electromotive force
event	the condition or state of an analog or digital signal

F

filters	digital or analog circuits that change the frequency characteristics of a signal
ft	feet

G

gain	factor by which a signal is amplified, sometimes expressed in decibels
GND	ground

H

hardware	physical components of a computer system, such as the circuit boards, plug-in boards, chassis, enclosures, peripherals, cables, and so on
Hz	hertz—the number of scans read or updates written per second

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
IC	integrated circuit
I_{EXx}	voltage excitation signal
in.	inches
interrupt	a computer signal indicating that the CPU should suspend its current task to service a designated activity
ITS	International Temperature Scale

K

K	(1) kelvin; (2) kilo—the prefix for 1,024, or 2^{10}, used with B in quantifying data or computer memory
kbytes/s	a unit for data transfer that means 1,000 or 10^3 bytes/s
kS	1,000 samples

L

LabVIEW	a graphical programming language
latch	digital device that stores the digital data based on a control signal
LED	light-emitting diode

M

m	meters
M	(1) Mega, the standard metric prefix for 1 million or 10^6, when used with units of measure such as volts and hertz; (2) mega, the prefix for 1,048,576, or 2^{20}, when used with B to quantify data or computer memory

MB	megabytes of memory
Mbytes/s	a unit for data transfer that means 2^{20} or 1,048,576 bytes/s
Measurement & Automation Explorer (MAX)	a controlled centralized configuration environment that allows you to configure all of your National Instruments DAQ, GPIB, IMAQ, IVI, Motion, VISA, and VXI devices

N

NI-DAQ	National Instruments driver software for DAQ hardware
NIST	National Institute of Standards and Technology
NMR	normal mode rejection
noise	an undesirable signal—electrical 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.
NPN	type of bipolar transistor
NTC	negative temperature coefficient

O

operating system	base-level software that controls a computer, runs programs, interacts with users, and communicates with installed hardware or peripheral instruments

P

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 workstations and offers a theoretical maximum transfer rate of 132 Mbytes/s.
peak to peak	a measure of signal amplitude—the difference between the highest and lowest excursions of the signal
PLC	power line cycles

PLF	power line frequency
Plug and Play devices	devices that do not require dip switches or jumpers to configure resources on the devices—also called switchless devices
port	(1) a communications connection on a computer or remote controller; (2) a digital port, consisting of four or eight lines of digital input and/or output
PTC	positive temperature coefficient
PXI	A rugged, open system for modular instrumentation based on CompactPCI, with special mechanical, electrical, and software features.

R

reading rate	the rate, in hertz, at which each sample is updated
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 24-bit resolution, one part in $2^{24} = 16{,}777{,}216$ resolution, and $5.96 \times 10^{-6}\%$ of full scale.
rms	root mean square—the square root of the average value of the square of the instantaneous signal amplitudes; a measure of signal amplitude
RSVD*x*	reserved
RTD	resistance temperature detector—a metallic probe that measures temperature based upon its resistance

S

s	second
S	sample
S/s	samples per second—used to express the rate at which a NI 435*x* samples an analog signal
sigma-delta	technology used for analog to digital conversion
sinter	to cause to become a coherent mass by heating without melting

system noise	a measure of the amount of noise seen by an analog circuit or an ADC when the analog inputs are grounded

T

thermistor	a semiconductor sensor that produces a repeatable change in electrical resistance as a function of temperature. Most thermistors have a negative temperature coefficient (NTC).
thermocouple	a temperature sensor created by joining two dissimilar metals. The junction produces a small voltage as a function of the temperature.
TTL	transistor-transistor logic

U

update	one or more analog or digital output samples. Typically the number of output samples in an update is equal to the number of channels in the output group.
update rate	the rate at which the measurement data is updated
USB	Universal Serial Bus

V

V	the basic unit of electromotive force, or electric “pressure” that causes electric current to flow. One volt is defined as the electromotive force to make one ampere current flow through a one ohm resistor.
VI	virtual instrument—(1) a combination of hardware and/or software elements, typically used with a PC, that has the functionality of a classic standalone instrument; (2) a LabVIEW software module (VI), which consists of a front panel user interface and a block diagram program
VirtualBench-Logger	a high-performance, easy-to-use, virtual instruments application program for use with the NI 435*x* devices
virtual channels	channel names that can be defined outside the application and used without having to perform scaling operations

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