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DAQ

NI 435x User Manual

High-Precision Temperature and Voltage Meters

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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). All National Instruments (NI) products are FCC Class A products.

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.

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 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 with EU Directives

Users in the European Union (EU) should refer to the Declaration of Conformity (DoC) for information* pertaining to the CE marking. 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/certification, search by model number or product line, and click the appropriate link in the Certification column.

* 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 National Instruments 4350/4351 devices 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.



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

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.

| | |
|-------------------------------|--|
| NI 435x | Refers to all NI 4350 and NI 4351 devices. |
| NI 435x for PXI, PCI, and USB | Refers to the NI 4350 and NI 4351 devices by form factor. |
| NI PCI-4351 | Refers to the NI 4351 for PCI. |
| NI PXI-4351 | Refers to the NI 4351 for PXI. |
| NI USB-4350 | Refers to the NI 4350 for USB. Software sometimes refers to this device as the NI DAQPad-4350. |

Related Documentation

This manual is one piece of the NI 435x documentation set. Refer to the following documents at ni.com/manuals for additional information that is relevant to the NI 435x devices.

- *Read Me First: Safety and Radio-Frequency Interference*
- Refer to the following software documentation at **Start»Programs»National Instruments»NI-435x»Documentation:**
 - *NI 435x LabVIEW Reference Help*
 - *NI 435x C/C++/CVI/VB Help*
- 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.

Examples

Complete the following steps to refer to the NI 435x examples through the NI Example Finder in LabVIEW:

1. Launch LabVIEW.
2. Select **Open**.
3. Select **Examples**.
4. Enter a keyword to search all available examples.

Introduction

This chapter describes the NI 435x high-precision temperature and voltage meters and describes the optional software and equipment.

About the NI 435x High-Precision DAQ Devices

The NI 435x devices for PXI, PCI, and USB feature accurate thermocouple and DC voltage meters. You also can take temperature measurements with resistance temperature detectors (RTDs) or thermistors, resistance measurements using built-in precision current sources, and current measurements using external shunt resistors. The NI 435x hardware is plug-and-play compatible, fully software calibrated, and compatible with a variety of operating systems.

NI 435x hardware has a 24-bit sigma-delta analog-to-digital converter (ADC) with differential analog inputs. The low-leakage construction and analog and digital filtering provide excellent resolution, accuracy, and noise rejection. Software-programmable ground-referencing enables you to reference a floating signal without compromising voltage measurements even if the floating signal is ground-referenced. Software-programmable open-thermocouple detection allows you to detect a broken thermocouple.

You can measure resistance up to 600 k Ω using the built-in 25 μ A precision current source on all NI 435x hardware, and up to 15 k Ω with the additional built-in 1 mA precision current source on the NI PXI/PCI-4351. Also, programmable TTL-compatible digital I/O (DIO) lines monitor TTL-level inputs, interface with external devices, and generate alarms.

A system based upon NI 435x hardware offers flexibility, performance, and compact size, making it ideal for service, repair, and manufacturing, and for use in industrial and laboratory environments.

Detailed specifications for the NI 435x 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. Refer to www.pxisa.org for more information.

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

Software Options for the NI 435x

You can use LabVIEW, LabWindows™/CVI™, Microsoft Visual Basic, C/C++, or VI Logger to program and use the NI 435x. This section provides details on the software choices available for the NI 435x.

What Is the NI-435x 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 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-435x 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-435x instrument driver is VXI plug-and-play compatible and also contains the source code, so you can examine and modify it. The NI-435x instrument driver works with LabVIEW, LabWindows/CVI, or conventional programming languages such as C, C++, and Visual Basic. Refer to the *NI 435x LabVIEW Reference Help* and the *NI 435x C/C++/CVI/VB Help* at **Start>Programs>National Instruments>NI-435x>Documentation**.

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.

Use the NI-435x instrument driver VIs with LabVIEW.

What Is LabWindows/CVI?

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

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

What Is VI Logger?

VI Logger equips you with the necessary software tools to define and execute a data logging task. With VI Logger, you can view real-time data, share data, and browse and manage historical data. Using VI Logger in Measurement & Automation Explorer (MAX) with such features as event detection and calculated channels, you can define advanced tasks without any programming. Using LabVIEW and the VI Logger VIs, you can execute a task, view live data, browse historical data, and build logging applications using all of the advanced programming capabilities of LabVIEW.

Refer to the [Creating a Task in VI Logger](#) section of this manual for information on using VI Logger.

Installing the Software

Refer to the *NI 435x Getting Started Guide* that ships with the NI 435x hardware or at ni.com/manuals for information about installing NI-435x instrument driver software and VI Logger software.

Installing the Hardware

To install the NI PXI-4351, NI PCI-4351, or NI USB-4350 hardware, complete the steps of the appropriate procedure as follows.



Cautions Follow proper ESD precautions to ensure you are grounded before installing the hardware. Refer to Appendix A, *Specifications*, for important safety and compliance information.

For safety information that is relevant to the NI 435x devices, refer to the *Read Me First: Safety and Radio-Frequency Interference* document in the NI 435x shipping kit or at ni.com/manuals.

NI PXI-4351

Complete the following steps and refer to Figure 1-1 to install the NI PXI-4351.

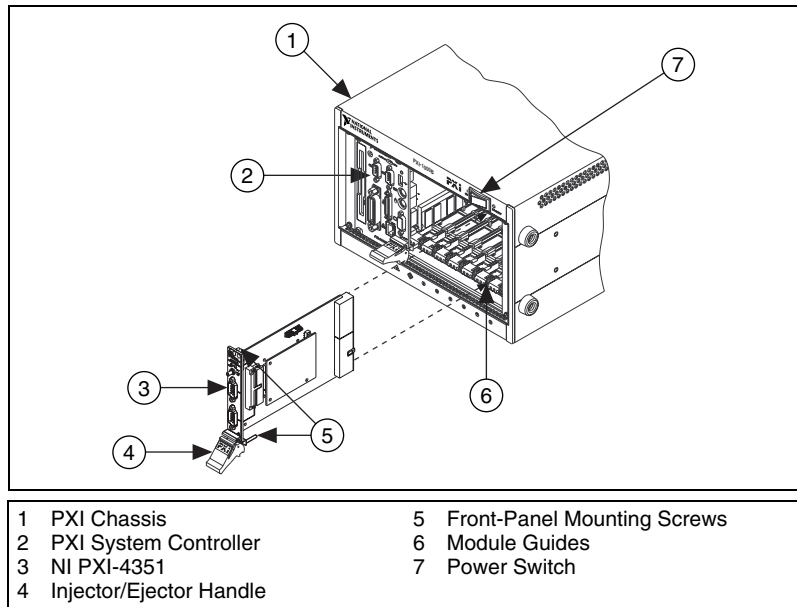


Figure 1-1. Installing the NI PXI-4351

1. Power off and unplug the PXI chassis.



Caution Before removing equipment covers or connecting or disconnecting any signal wires, refer to the *Read Me First: Safety and Radio-Frequency Interference* document in the NI PXI-4351 shipping kit or at ni.com/manuals.

2. Remove the filler panel from an unused PXI slot.
3. Touch any metal part of the chassis to discharge static electricity.
4. Ensure that the injector/ejector handle on the NI PXI-4351 is not latched and swings freely.
5. Place the NI PXI-4351 edges into the device guides at the top and bottom of the chassis.
6. Slide the NI PXI-4351 into the PXI slot to the rear of the chassis.
7. When you begin to feel resistance, pull up on the injector/ejector handle to fully insert the NI PXI-4351.
8. Secure the NI PXI-4351 to the chassis front panel mounting rail using the front-panel mounting screws.
9. Plug in and power on the PXI chassis.

NI PCI-4351

Complete the following steps and refer to Figure 1-2 to install the NI PCI-4351:

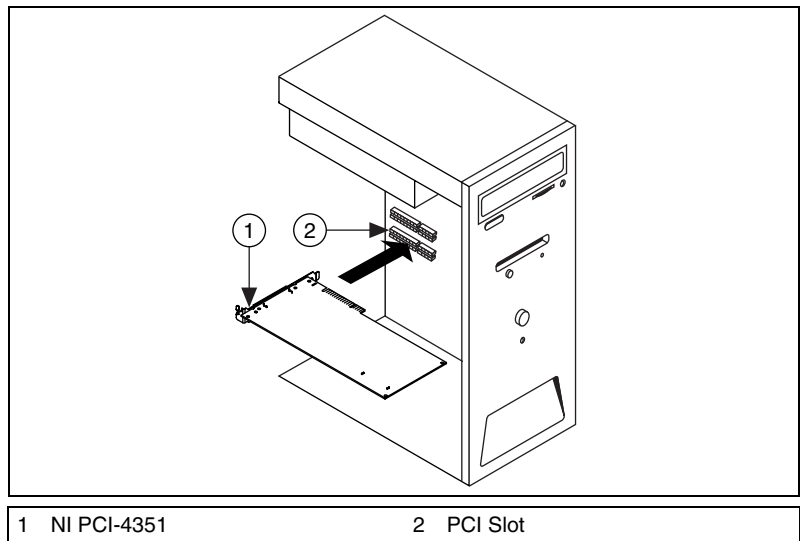


Figure 1-2. Installing the NI PCI-4351

1. Power off and unplug the computer.



Caution Before removing equipment covers or connecting or disconnecting any signal wires, refer to the *Read Me First: Safety and Radio-Frequency Interference* document in the NI PCI-4351 shipping kit or at ni.com/manuals.

2. Remove the computer cover and/or the expansion slot cover.
3. Touch any metal part of the computer to discharge static electricity.
4. Insert the device into a PCI slot. Gently rock the device into place. Do *not* force the NI PCI-4351 into place.
5. Secure the device mounting bracket to the computer back panel rail.
6. Replace the computer cover, if applicable.
7. Plug in and power on the computer.

NI USB-4350

To install the NI USB-4350, connect the cable from the computer USB port to an available USB port on the NI USB-4350. Figure 1-3 shows the USB cable and its connectors.

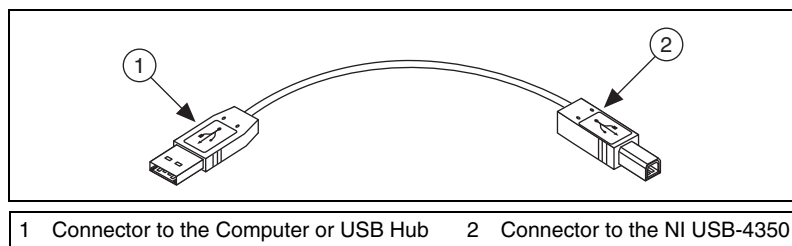


Figure 1-3. USB Cable and Connectors

When you connect the NI USB-4350 to the PC, the computer recognizes the NI USB-4350 immediately, and the LED on the device front panel blinks or lights up, depending upon the status of the NI USB-4350.

Power Considerations

The NI USB-4350 is powered on only when the USB cable connects the NI USB-4350 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. At times, 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 power supply. This over-current condition makes the LED blink in the power supply overload pattern described in the *LED Patterns* section.



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 By default, the NI USB-4350 remains fully powered during suspend mode. To change the settings that determine the behavior of the NI USB-4350 during suspend mode, refer to one of the following locations:

- The *Set_DAQ_Device_Info* section of the *Traditional NI-DAQ (Legacy) Function Reference Help*, located at **Start»Programs»National Instruments»NI-DAQ»Traditional NI-DAQ (Legacy) Function Reference Help**.
- The *Set DAQ Device Information (Device Setting VI)* section of the *LabVIEW Help*, located at **Start»Programs»National Instruments»LabVIEW 7.x»VI, Function, & How-To Help**.

LED Patterns

If the LED comes on after the NI USB-4350 is connected to the computer, the device is functioning properly. If the LED remains off or blinks, refer to Table 1-1.

Table 1-1. LED State Patterns for the NI USB-4350 States¹

| LED | 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 is 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 the device driver is improperly installed or system resources are unavailable. Check the software installation. |

Table 1-1. LED State Patterns for the NI USB-4350 States¹ (Continued)

| LED | State | Description |
|----------|----------------------|--|
| 3 blinks | Power supply failure | The internal power supply shut down. Refer to the <i>Power Considerations</i> section for more information. |
| 4 blinks | General error state | Contact NI. Refer to Appendix C, <i>Technical Support and Professional Services</i> , for contact information. |

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

Safety

For safety information that is relevant to the NI 435x devices, refer to the *Read Me First: Safety and Radio-Frequency Interference* document in the NI 435x shipping kit or at ni.com/manuals.

Configuring the Hardware in MAX

To configure the NI 435x hardware in MAX, complete the following steps:

1. Double-click the **Measurement & Automation** icon on the desktop to open MAX.
2. Expand **Devices and Interfaces**.
3. Expand **Traditional NI-DAQ (Legacy) Devices**.
4. Verify that the NI 435x device name appears under Traditional NI-DAQ (Legacy) Devices.
5. If the NI 435x device name does not appear, press <F5> to refresh the view in MAX. If the device is still not recognized, refer to ni.com/support/install for troubleshooting information.
6. Right-click the NI 435x device name and select **Properties** to open the Configuring Device window. Configure the device properties, including accessories in the Accessory tab.
7. Click **Apply** to accept the changes.
8. Click **Test Resources** in the System tab of the Configuring Device window.
9. When the self-test finishes, a message indicates successful verification or if an error occurred. If an error occurs, refer to ni.com/support/install for troubleshooting information.
10. Click **OK** to close the Configuring Device window.

Creating a Task in VI Logger

This section explains how to configure and run a task using VI Logger with the NI 435x hardware and how to view or export the resulting data.



Caution To use VI Logger with the NI 435x devices, you must activate VI Logger. Refer to ni.com/license to activate VI Logger.

Before you create a VI Logger task, you should confirm that you have properly configured the NI 435x hardware and associated accessories (if applicable) as outlined in [Configuring the Hardware in MAX](#).

Using Virtual Channels with VI Logger

Before you create a VI Logger task for an NI-DAQ traditional virtual channel, you need to first create the virtual channel and test it.

Creating Virtual Channels

Complete the following steps to create the traditional virtual channels to use in a data logging task.

1. Launch the **Measurement & Automation** icon.
2. In the MAX configuration tree, right-click **Data Neighborhood** and select Create New from the pop-up menu.
3. The **Create New** wizard opens. Select **Traditional NI-DAQ (Legacy) Virtual Channel** and follow the wizard instructions to create a new virtual channel.

Modifying Virtual Channels

Complete the following steps to modify a virtual channel.

1. In the configuration tree of MAX, right-click a virtual channel under **Data Neighborhood**.
2. Select **Properties**.
3. Make any modifications necessary in the **Configuration** dialog box that appears.
4. Click **OK** when you are finished.



Note Click the **Advanced...** button to view and change additional channel properties, including Auto-zero Mode, Notch Filter Frequency, Open Thermocouple Detection, and Ground Referencing.

Testing Virtual Channels

The Virtual Channel Test Panels show actual readings so you can directly control the different channels you have configured. Complete the following steps to test the virtual channels.

1. In the configuration tree of MAX, right-click a virtual channel under **Data Neighborhood**.
2. Select **Test**.
3. View the readings and change any parameters in the **Virtual Channel Test Panels** dialog box.
4. Click **Close** when you are finished.

Creating and Configuring a Task

When you configure a logging task, VI Logger provides feedback if any choices you make are invalid. Complete the following steps to create a data logging task.

1. Launch VI Logger by selecting **Start»Programs»National Instruments»VI Logger»VI Logger in MAX**.
2. In the configuration tree in MAX, right-click **VI Logger Tasks** and select **Create New**. The **Create New** dialog box appears.
3. Select **Using Traditional NI-DAQ (Legacy)** and click **Finish**. In the MAX configuration tree, the newly created task is selected and the **Task Attributes** view is selected.



Note If you can only use NI-DAQmx rather than Traditional NI-DAQ (Legacy), you must still activate the VI Logger license. Refer to ni.com/license for more information.

VI Logger automatically gives the task a unique default name, which appears under VI Logger Tasks. You can rename the task by right-clicking on the task name and selecting **Rename Task**.

4. In the **Acquisition Settings** section, enter the following fields:
 - a. In the **Device** field, select the device you are using.
 - b. Select **Filter Frequency**. Refer to Table 2-1, *Filtering and Sample Rates*, to determine the reading rate.
5. In the **Buffer Settings** section, you can define buffering parameters for the task. With these parameters, you can modify the performance of VI Logger, specifically if you are trying to log data at a high rate.



Tip You cannot log data from more than one NI-DAQ device per task. However, you can define one task for each device and can run more than one task at the same time.

6. In the **Logging Conditions** section, you can control datalogging using one of the digital lines. Refer to the *Using Digital Lines to Control Datalogging* section of the *VI Logger Help* by selecting **Help»Help Topics»VI Logger»VI Logger** in MAX.



Note The NI 435x hardware does *not* support digital or analog triggering. By default, the **Start acquisition on trigger** checkbox is unchecked. If you select the checkbox, you receive an error when you start the task; this error indicates that triggering is not supported. Refer to step 6 above for alternative software triggering.

Selecting Channels for a VI Logger Task to Acquire and Log Data

For each VI Logger task you configure, you can select which specific channels acquire and log data within that task.

Complete the following steps to set up the channels that acquire and log data.

1. With a VI Logger Task selected, click the **Virtual Channels** tab to open the Virtual Channels view.
2. Right-click the **Events** column heading and select **Events** to enable or disable the information displayed in the table. Refer to the Measurement & Automation Explorer Help for VI Logger by selecting **Help»Help Topics»VI Logger»VI Logger** for more information about the information columns in the Virtual Channels view.
3. The **Active Channel** column displays all the virtual channels you have created in MAX for your device. To enable logging for each channel, place a checkmark in the **Log Enabled?** checkbox to the right of each channel name.



Tip To add a virtual channel, click **Create channel** and follow the instructions in the Create New Channel wizard.

Refer to the *Creating Calculated Channels* section for information about creating calculated channels for VI Logger tasks.

Configuring Events for a Logging Task

You can configure events to be logged in your task that will appear in the Events view. Complete the following steps to configure the events for a logging task.

1. In the NI-DAQ Channels view, right-click the **Channels** column and select **Events**.
2. Check and uncheck the desired events to select which events to display for the channels.
3. You also can right-click the table cells to access more options to modify these conditions.

Creating Calculated Channels

You can set up mathematical equations that use virtual channels using math channels. For example, for channels **Channel 0** and **Channel 1**, you could enter the equation `Channel 0 - Channel 1`, to subtract one from the other. The result would be a calculated channel.

Complete the following steps to create a calculated channel.

1. Click the **Calculated Channels** tab to display the **Calculated Channels** view.
2. Click **Create channel**. The **Math Expression Editor** dialog box appears where you can define a math channel.
3. In the **Channel Settings** section in the **Name** field, enter an appropriate name for the math channel.
4. In the **Units** field, enter the appropriate unit type.
5. In the **Minimum** and **Maximum** fields, enter a range of units that applies to the math channel.
6. In the **Formula Settings** section in the **Formula** field, click the down arrow, and select one of four formulas to apply to the math channel:
 - **Ax (Op) By + C**—A linear combination formula. Fill in fields **A**, **Channel X**, **Operation**, **B**, **Channel Y**, and **C** with the appropriate values.
 - **db x/y**—A measurement of noise (db)—power base 10. Select the channels you want for **Channel X** and **Channel Y** fields.
 - **dBVx**—A single channel noise measurement. Select the channel you want for the **Channel X** field.
 - **User Defined**—A formula that you create.
7. Click **OK**.

Accessories

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

- Isothermal terminal blocks—TBX-68T, CB-68T, and TC-2190
- Terminal blocks—TBX-68
- Shielded and ribbon cables

For more information about these products, contact NI or search for NI PXI-4351, NI PCI-4351, or NI USB-4350 at ni.com/catalog.

Operating the NI 435x Device

This chapter describes how to use the NI 435x 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 435x Device

To minimize the effects of thermal drift and to ensure the specified accuracy, allow the NI 435x 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 435x device warms up for 30 minutes.

Choosing a Measurement Mode

You can configure the analog input channels for measuring outputs of various transducers, as follows:

- Voltage
- Thermocouples
- Resistors
- RTDs



Note When you are using Traditional NI-DAQ (Legacy) virtual channels in VI Logger, the measurement mode is chosen by the specified sensor type.

Available Ranges

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 resistance mode has six corresponding input ranges when used with the built-in 25 μ A current source on the NI PXI-4351, NI PCI-4351, and NI USB-4350: 25 k Ω , 50 k Ω , 100 k Ω , 150 k Ω , 300 k Ω , and 600 k Ω . With the additional built-in 1 mA current source on the NI PXI-4351 or NI PCI-4351, resistance mode also has 625 Ω , 1.2 k Ω , 3.75 k Ω , 7.5 k Ω , and 15 k Ω as possible input ranges.

For the best measurement results, specify the upper and lower limit values of the measurement when configuring the NI 435x. When scanning multiple channels, the NI 435x uses a single range, which is the widest range of any channel in the scan list.



Note Specify the limit values 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 435x takes a new measurement. This rate has a direct relationship with the digital filter built into the ADC on the NI 435x.

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.

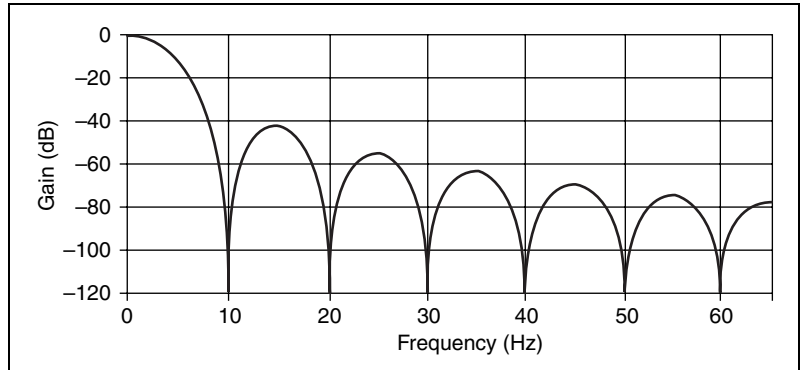


Figure 2-1. Digital Filter Characteristics for 10 Hz Setting

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 k Ω or voltage measurements with more than 25 k Ω 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 435x 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 filter settings reject harmonics of particular frequencies.

Table 2-1. Filtering and Sample Rates

| NI-DAQ Notch Filter Frequency Setting (Hz) | NI-435x | | Equivalent Filter Setting | | Harmonics of Noise Frequencies Rejected (Hz) | Single- Channel Measurement Reading Rate (readings/s) | Multiple- Channel Measurement Reading Rate* (readings/s) | |
|---|--------------|-----------------|------------------------------|-----------------|--|---|--|-------|
| | PLF* (Hz) | Reading Rate | PLC† | PLF* (Hz) | | | Reading Rate* (readings/s) | |
| 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.
‡ To determine the reading rate per channel, divide this value by the number of channels in the scan.
** 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 435x, 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 435x

Using Programmable Ground-Referencing

The NI 435x 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 M Ω 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 Programmable ground-referencing applies to voltage and thermocouple modes only.

Using Programmable Open-Thermocouple Detection

The NI 435x 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 M Ω 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. 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 [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

A thermocouple, which measures temperature, 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 435x 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, $V_{\text{thermocouple}}$, and the cold-junction voltage, $V_{\text{cold-junction}}$. The method of compensating for these unwanted cold-junction voltages is called cold-junction compensation (CJC).

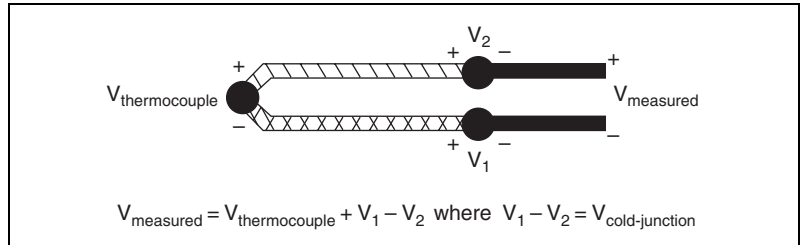


Figure 2-2. Effect of the Cold-Junction

With the NI 435x, you can perform CJC in software in three ways, as follows:

- Using the built-in thermistor temperature sensor on an NI 435x 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 TC-2190, TBX-68T, and CB-68T accessories.

If you are using NI-435x and have configured the accessory in MAX, use thermocouple mode with the CJC setting of Auto to enable the software to perform cold-junction compensation on all configured thermocouple channels.

If you are using VI Logger and have configured the accessory in MAX, use the Built-In option for the CJC source on the Traditional NI-DAQ (Legacy) virtual channel.

- Providing a constant user value.

If you are using NI-435x, use the CJC setting of Manual on the configured thermocouple channel.

If you are using VI Logger, use and specify the User-Value option for the CJC source on the Traditional NI-DAQ (Legacy) virtual channel.

- Providing your own temperature sensor for CJC, in which case you must complete all measurement acquisition and computational steps. For example, if you are using a thermistor as a CJC sensor, you must complete the following steps:
 1. Measure the resistance of the thermistor cold-junction sensor, $R_{\text{thermistor cold-junction}}$, and compute the cold-junction temperature, $T_{\text{cold-junction}}$, using the thermistor resistance-temperature conversion formula.
 2. From this temperature of the cold-junction, $T_{\text{cold-junction}}$, compute the equivalent thermocouple voltage, $V_{\text{cold-junction}}$, for this junction using a standard thermocouple conversion formula.

3. Measure the voltage, V_{measured} , and add the cold-junction voltage, $V_{\text{cold-junction}}$, computed in step 2.
4. Convert the resulting voltage to temperature using a standard thermocouple conversion formula.
5. Use the CJC setting of Manual on the configured thermocouple channel.

Connecting the Thermocouple

The NI 435x accessories—the TC-2190, TBX-68T, and CB-68T for the NI 435x 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 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 435x is powered on and ± 17 VDC when the NI 435x is powered off.

The NI 435x analog inputs are protected against damage from voltages within ± 42 VDC in all ranges when powered on and ± 17 VDC when the NI 435x 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 435x accessory in the same scan by choosing the 25 k Ω range for measuring the thermistor. These ranges offer the best resolution, noise rejection, and accuracy.



Note If scanning thermocouples and other transducers, the NI 453x device uses the widest range for all channels, which can make the thermocouple measurements appear noisier.

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 removes any offset errors in the measurement. Analog channel 1 (CH1) on the 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. Hence, you can compensate for any residual offset error the NI 435x may have. This compensation is especially useful when the NI 435x 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 435x 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 435x device.

On all the NI 435x 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 VI Logger in MAX with Traditional NI-DAQ (Legacy) 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 $^{\circ}\text{C}$. 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 435x 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 435x may exhibit additional errors. To minimize these errors, keep the thermocouples, the NI 435x, 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 435x, and its accessories.

Measuring DC Voltage

Connecting the DC Voltage Signal

The NI 435x accessories—the TBX-68T, CB-68T, TBX-68, and TC-2190 for the NI 435x for PXI, PCI, and USB—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 435x analog inputs are protected against damage from voltages within ± 42 VDC in all ranges when powered on and ± 17 VDC when the NI 435x 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 435x is powered on and ± 17 VDC when the NI 435x is powered off.

Input Ranges

The NI 435x 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 435x 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 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 435x uses the widest voltage range for all channels, which can make the lower voltage signal measurements appear noisier.

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 removes any offset errors in the measurement. Analog channel 1 (CH1) on the TBX-68T, TC-2190, and CB-68T is dedicated for Auto Zero. CH1+ is connected to CH1– on these accessories. When using a TBX-68 accessory, 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 435x may have. This compensation is especially useful when the NI 435x 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 435x 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 435x.

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



Note When using VI Logger in MAX with Traditional NI-DAQ (Legacy) virtual channels with the accessories, including the 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 k Ω , 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 435x 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 435x may exhibit additional errors. To minimize these errors, keep the signal source, the NI 435x, 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 435x accessory. Avoid using dissimilar metal wires in connections. Also, minimize temperature gradients in the space enclosing the signal source, the NI 435x, and its accessories.

Measuring Resistance and Measuring Temperature with RTDs and Thermistors

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.

The NI 435x accessories—the TBX-68T, CB-68T, and TBX-68 for the NI 435x for PXI, PCI, and USB—are designed to be used with RTDs,

thermistors, and resistors. Consult the accessory installation guide for instructions on how to configure the terminal block.

Using the Current Source

The NI PXI-4351, NI PCI-4351, and NI USB-4350 feature a 25 μA precision current source, which supplies excitation for a total maximum load resistance of 600 $\text{k}\Omega$. The NI PXI/PCI-4351 has an additional precision current source, which supplies 1 mA excitation for a total maximum load resistance of 15 $\text{k}\Omega$.

These resistances can be in the form of RTDs, thermistors, or any other resistor. The calibrated value of the current source is stored onboard, and NI-435x uses this precise value in its computations.

Connecting Resistors

To measure resistance, you must pass current through the device and measure the resulting voltage. NI-435x returns resistance measurements by dividing the measured voltage by the calibrated value of the current source stored onboard. However, any resistance in the lead wires that connect the measurement system to the resistor adds errors to the readings.

Figure 2-3 shows an example of an RTD connected to the NI 435x accessory using two leads. The NI 435x accessory also supplies a constant current source, I_{EX} , to excite the resistor. This type of connection is known as a 2-wire connection. The voltage measured corresponds to the voltage drops across the resistor under test and across the two lead resistances, R_L .

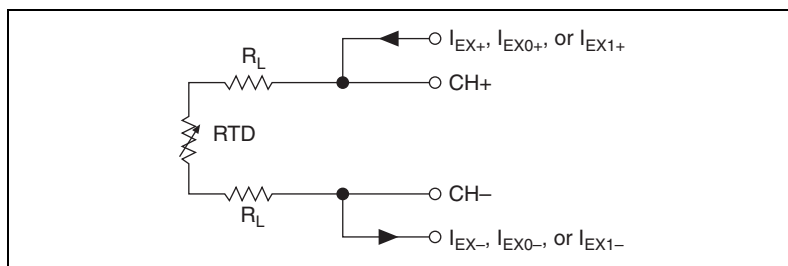


Figure 2-3. 2-Wire Measurement, where an RTD is the Resistor Under Test

For example, a lead resistance R_L of 0.3 Ω in each wire adds a 0.6 Ω error to the resistance measurement.

If you are using lead lengths greater than 10 ft, you may need to compensate for this error. To compensate for lead resistance, the preferred

measurement method is to use a 4-wire connection, where one pair of wires carries the excitation current and the other pair of wires senses the voltage across the resistor. Because the input impedance of the channel (CH+ and CH-) is very high, practically no current flows through the sensing wires, the lead resistance error of R_{L2} and R_{L3} is negligible. Figure 2-4 illustrates this configuration.



Note To minimize the error due to lead resistance, connect the voltage sense terminals (CH+ and CH-) as close as possible to the resistor under test.

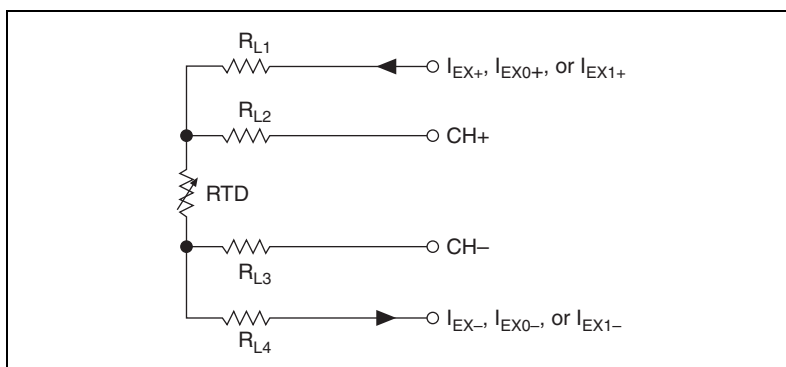


Figure 2-4. 4-Wire Measurement, where an RTD is the Resistor Under Test

Alternatively, you can use a 3-wire connection. Figure 2-5 shows a 3-wire resistor configuration with a current source. In this configuration, the resistance of only one lead, R_{L1} , adds error to the measurement.

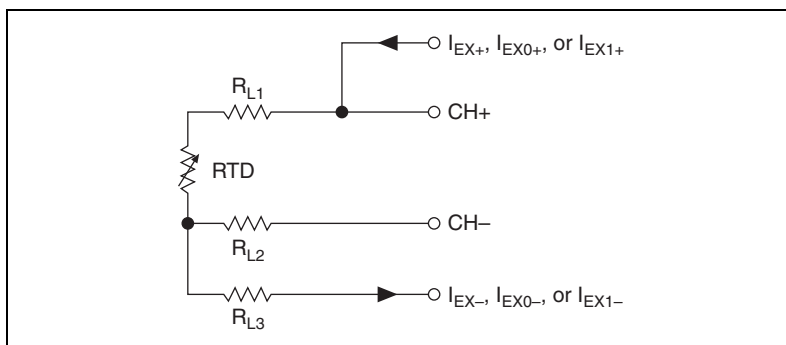


Figure 2-5. 3-Wire Measurement, where an RTD is the Resistor Under Test

Another variation of the 3-wire configuration is shown in Figure 2-6. In this configuration, the effects of the same lead resistance cancel out as long as

all three wires have the same lead resistance. However, it uses two input channels per resistor while the previous configurations use only one.

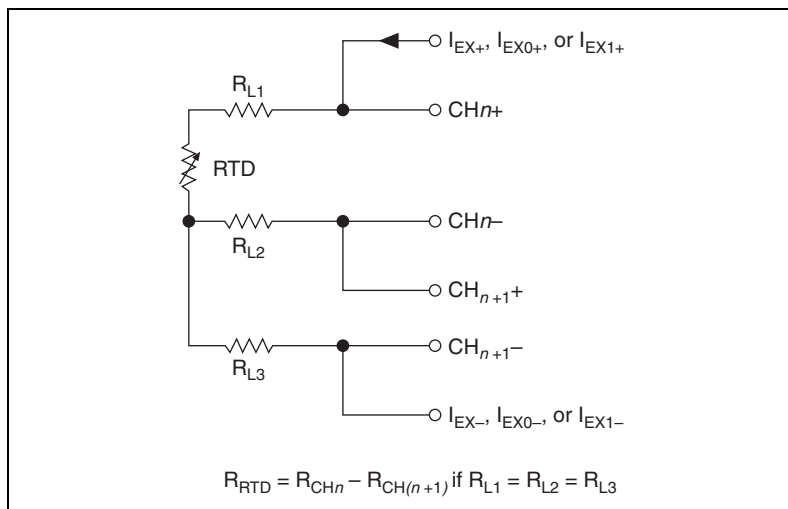


Figure 2-6. 3-Wire Measurement and Lead Wire Resistance Compensation, where an RTD is the Resistor Under Test



Note For best results, use the 1 mA current source when using the NI 4351 with RTDs or resistors with resistances below 1 k Ω . For resistances above 1 k Ω or with the NI 4350, use the 25 μ A current source to avoid self-heating. Refer to the [Self-Heating](#) section for further details.

You can use the same current excitation for several resistors as long as you do not exceed the maximum load and are within the common-mode voltage specification listed in Appendix A, [Specifications](#). Refer to Figures 2-7 and 2-8 for examples of how you can use different transducers connected to analog channels in the same measurement setup.

Input Ranges

With the 25 μ A current source, the NI PXI-4351, NI PCI-4351, and NI USB-4350 have six ranges for resistance measurements: 25 k Ω , 50 k Ω , 100 k Ω , 150 k Ω , 300 k Ω , and 600 k Ω . These ranges correspond to the six input ranges available for measuring DC voltages developed across resistors: ± 625 mV, ± 1.25 V, ± 2.5 V, ± 3.75 V, ± 7.5 V, and ± 15 V. The NI PXI/PCI-4351 has six additional ranges of 625 Ω , 1.25 k Ω , 2.5 k Ω , 3.75 k Ω , 7.5 k Ω , and 15 k Ω with the 1 mA current source.

The NI 435x 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 its input range and that the total resistance connected to the current excitation source does not exceed its maximum load.

To determine the most suitable input range for the application, estimate the voltage developed across the resistor by following the procedure outlined in Figures 2-7 and 2-8. Estimate the common-mode voltage at the inputs, and verify that the range you select can handle that common-mode voltage. Refer to the *Maximum Working Voltage* section of Appendix A, *Specifications*, for the maximum voltage per range.

To determine if the current excitation source can handle the load you are connecting to it, calculate the total load by adding the resistance value of all resistors, RTDs, and thermistors connected in series to the current excitation. Use the maximum resistance value that the RTDs and thermistors will reach in your measurements. Verify that this load is within the allowed limits. Refer to the *Excitation* section of Appendix A, *Specifications*, for the maximum load resistance.

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

The NI 435x 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 435x is powered on and ± 17 VDC when the NI 435x is powered off.

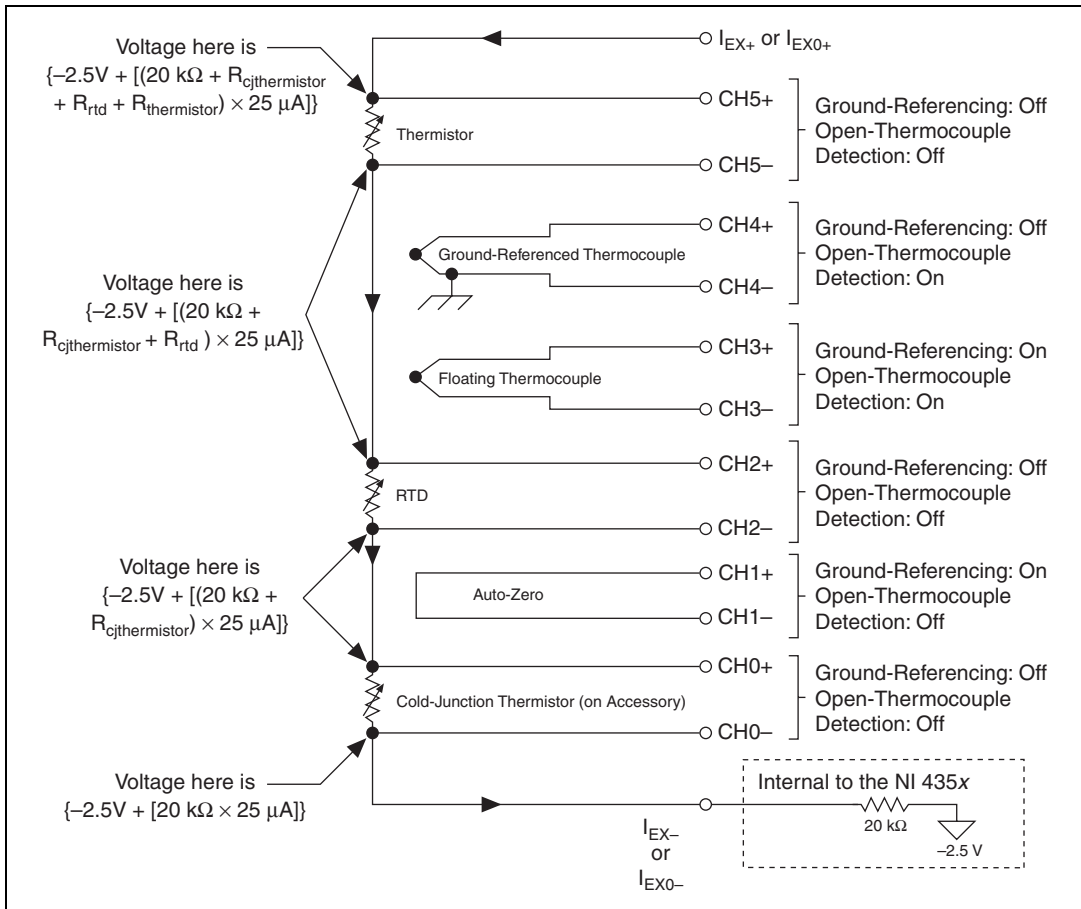


Figure 2-7. Multiple Transducer Connections to Analog Channels in One Measurement Setup, Channels 0–5

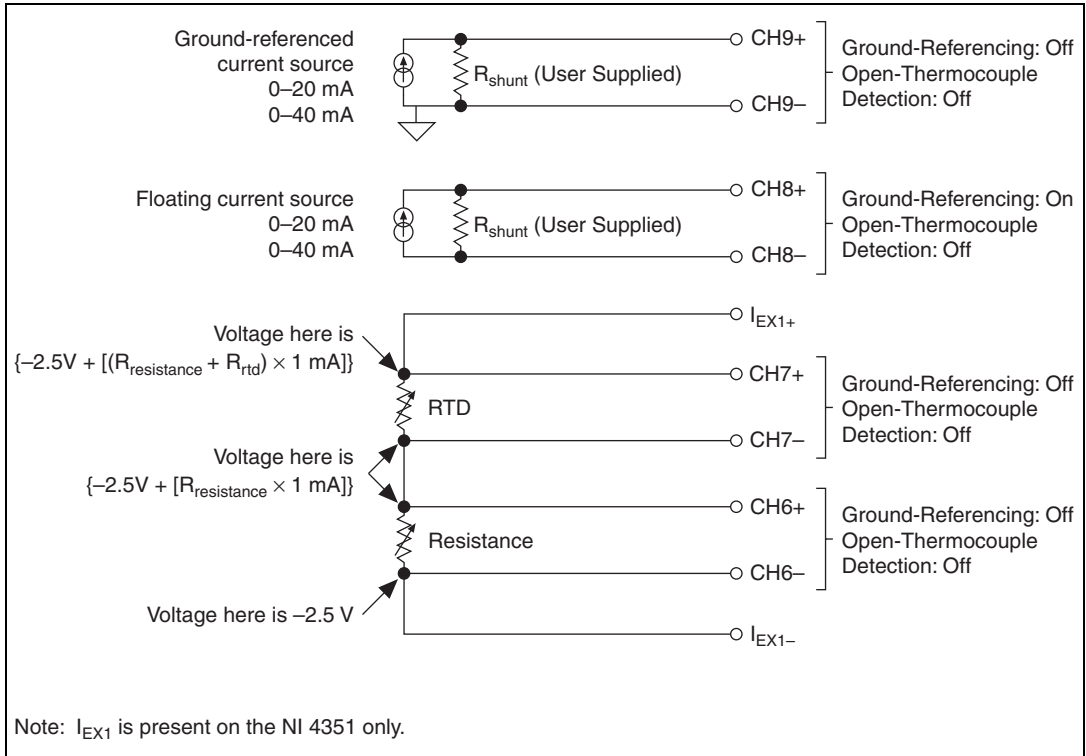


Figure 2-8. Multiple Transducer Connections to Analog Channels in One Measurement Setup, Channels 6–9

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 $^{\circ}\text{C}$.

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

RTDs can be difficult to measure because they have relatively low resistance (100 Ω) that changes only slightly with temperature (less than 0.4 $\Omega/^{\circ}\text{C}$). 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, 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 $^{\circ}\text{C}$ to 100 $^{\circ}\text{C}$, divided by the resistance at 0 $^{\circ}\text{C}$, divided by 100 $^{\circ}\text{C}$ as follows:

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

where R_{100} is the resistance of the RTD at 100 $^{\circ}\text{C}$, and R_0 is the resistance of the RTD at 0 $^{\circ}\text{C}$.

For example, a 100 Ω platinum RTD with $\alpha = 0.00385$ measures 138.5 Ω at 100 $^{\circ}\text{C}$. Figure 2-9 shows a typical resistance-temperature curve for a 100 Ω platinum RTD.

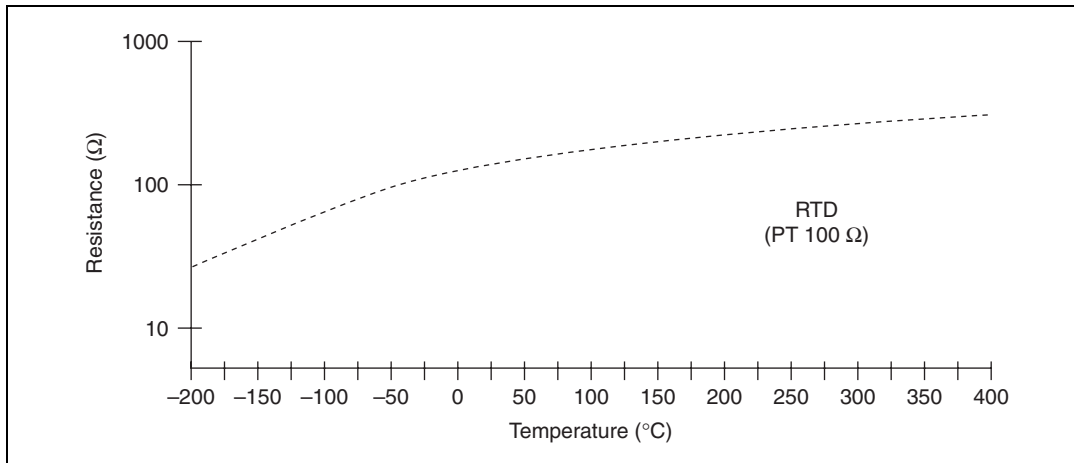


Figure 2-9. Resistance-Temperature Curve for a 100 Ω Platinum RTD

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:

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

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 $^{\circ}\text{C}$; A , B , and C are the Callendar-Van Dusen coefficients shown in Table 2-4; and T_{RTD} is the temperature in $^{\circ}\text{C}$. For temperatures above 0 $^{\circ}\text{C}$, coefficient C equals 0. Therefore, for temperatures above 0 $^{\circ}\text{C}$, this equation reduces to a quadratic:

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

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 NI software packages, such as NI-435x, 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

You can use signal connection techniques described in the [Connecting Resistors](#) section for any RTD.

The preferred RTD measurement method is to use a 4-wire connection, as shown in Figure 2-4, to minimize errors due to lead resistance. For example, if you connect an RTD in a 2-wire configuration as shown in Figure 2-3, a lead resistance, R_L , of 0.3 Ω in each wire results in a 0.6 Ω error. For a platinum RTD with $\alpha = 0.00385$, this error equals a 0.6 $\Omega / (0.385 \Omega / ^\circ\text{C}) = 1.6 \text{ } ^\circ\text{C}$ error. By connecting the RTD in a 4-wire configuration, this error is no longer present in the measurement.

Alternatively, you can use a 3-wire RTD configuration, as shown in Figures 2-5 and 2-6.



Note In the 3-wire connections shown in Figure 2-6, the effects of the lead-wire resistance cancel out as long as all three wires have the same lead resistance, while in the connections shown in Figure 2-5 the resistance of only one lead adds error to the measurement.

You can use the same current excitation for several resistors as long as you do not exceed the maximum load and are within the common-mode voltage specification. Refer to the [Input Ranges](#) section in the [Connecting Resistors](#) section for more information about connection precautions and for examples 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 k Ω . For resistances above 1 k Ω or with the NI 4350, use the 25 μ A 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 $-100 \Omega/^{\circ}\text{C}$ at room temperature. Higher resistance thermistors can exhibit temperature coefficients of $-10 \text{ k}\Omega/^{\circ}\text{C}$ or more. In comparison, a 100 Ω platinum RTD has a sensitivity of only $0.4 \Omega/^{\circ}\text{C}$. 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 $^{\circ}\text{C}$) 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 $^{\circ}\text{C}$. Figure 2-10 shows the resistance-temperature curve for a 5,000 Ω thermistor. The curve of a platinum 100 Ω RTD also is shown for comparison.

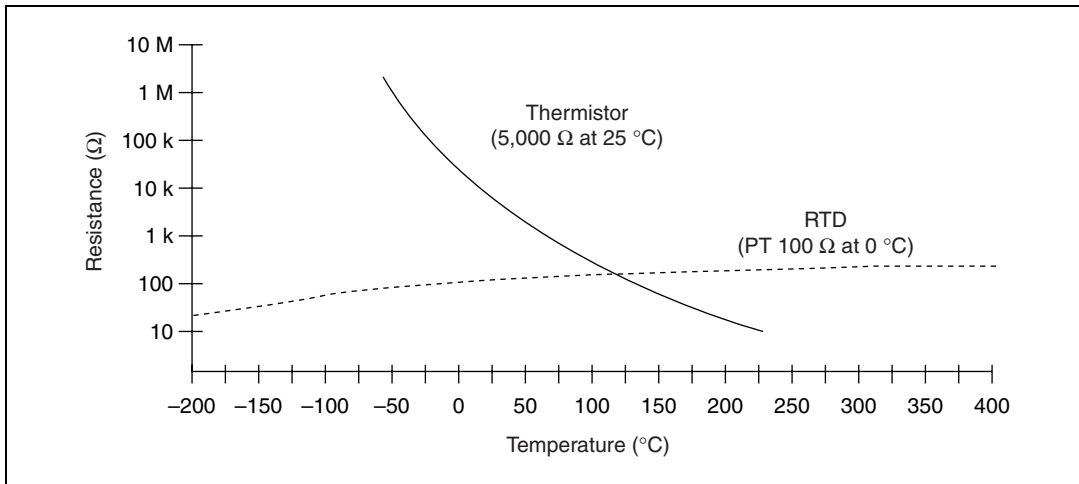


Figure 2-10. Resistance-Temperature Curve of a Thermistor

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:

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

Where $T(\text{K})$ is the temperature in kelvin, equal to $T(^{\circ}\text{C}) + 273.15$, 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

You can use signal connection techniques described in the [Connecting Resistors](#) section for any thermistor.

The high resistance and high sensitivity of the thermistor simplify the necessary measurement circuitry and signal conditioning. 3-wire or 4-wire connections, as shown in Figures 2-4, 2-5, and 2-6, are not necessary. The value of the lead resistance is negligible compared to the resistance value of the thermistor. Therefore, a 2-wire connection, as shown in Figure 2-3, is sufficient.

You can use the same current excitation for several resistors as long as you do not exceed the maximum load and are within the common-mode voltage specification. Refer to the [Input Ranges](#) section in the [Connecting Resistors](#) section for more information about connection precautions and for examples 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 k Ω to avoid self-heating. Refer to the [Self-Heating](#) section for further details.

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 removes any offset errors in the measurement. Analog channel 1 (CH1) on the TC-2190, TBX-68T, and CB-68T is dedicated for Auto Zero. CH1+ is connected to CH1– on these accessories. When using a TBX-68 accessory, 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. This is especially useful when the NI 435x is operating at an ambient temperature other than that of calibration (23 °C typical).

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 2-7 and 2-8 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 if the measured resistor is connected to external circuits that change the effective resistance.

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

The [Connecting Resistors](#) section discusses whether to use 2-wire, 3-wire, or 4-wire setups, and 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 Measurements

| Measured Resistance (Ω) | Measurement Technique |
|---|---------------------------|
| $R \leq 1 \text{ k}\Omega$ | 4-wire |
| $1 \text{ k}\Omega < R \leq 10 \text{ k}\Omega$ | 4-wire or 3-wire |
| $R > 10 \text{ k}\Omega$ | 4-wire, 3-wire, or 2-wire |

Self-Heating

The current source on the NI 435x is designed so that 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 and heats the resistive devices. This self-heating 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 that is 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 435x 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 435x may exhibit additional errors. To minimize these errors, keep the signal source, the NI 435x, 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 435x accessory. Avoid using dissimilar metal wires in connections. Also, keep out temperature gradients in the space enclosing the signal source, the NI 435x, and its accessories.

Using Digital Inputs and Outputs

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

You can use the DIO lines as an interface to control processes, to control events such as turning on and off heaters, relays, motors, or lights, to generate patterns for testing, and to 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 LabVIEW or NI-435x, set up the analog acquisition configuration, poll the digital input line for the trigger condition, and start the analog acquisition after receiving the trigger.

Connecting the Digital Input and Output

All NI 435x accessories are designed to be used for DIO. Refer to the accessory installation guide for instructions on how to connect the DIO lines. Figure 2-11 shows examples of how to connect DIO lines 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 435x for PXI, PCI, and USB, 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.

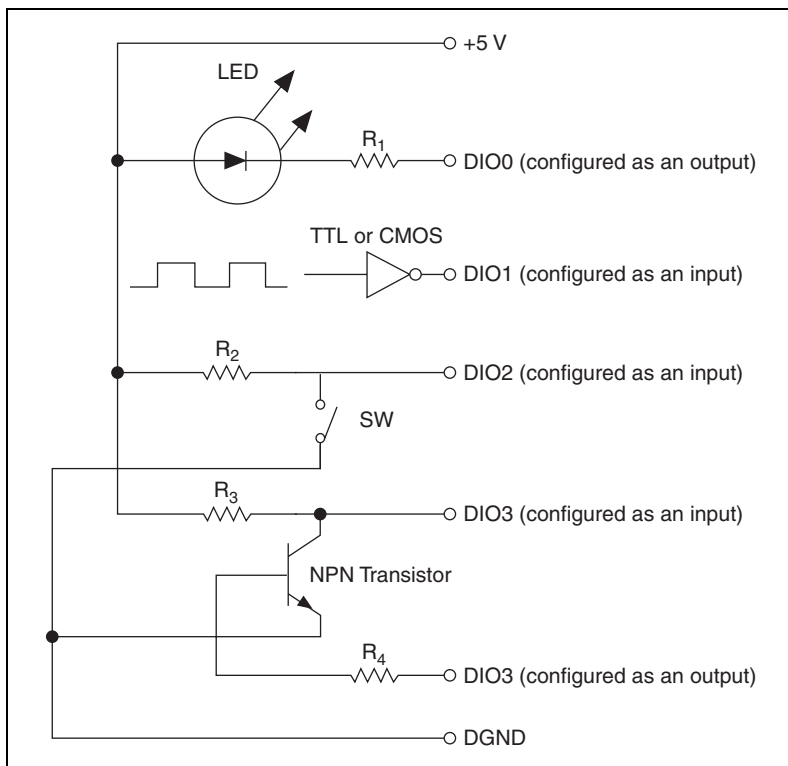


Figure 2-11. Examples of DIO Applications



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 435x 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 inadequate for the application, use the analog input channels to measure the voltage of the digital signal you want to measure. Determine the logic level based on the thresholds of the logic family of the digital signal. Table 2-6 shows 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. | | |

Specifications

This appendix lists the specifications of the NI 4350 and NI 4351. These specifications are for a 15 °C to 35 °C ambient temperature range within one year of calibration 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, TBX-68T, or CB-68T) is in the 0 °C to 15 °C and 35 °C to 55 °C temperature range.

Accuracy Specifications

Thermocouple Accuracy*

| Thermocouple Type | °C | Error (°C) 15 °C to 35 °C, 1 Year | | | 0 °C to 15 °C, 35 °C to 55 °C | |
|-------------------|-------|--------------------------------------|-------|-------|---|--|
| | | Filter Setting | | | Temperature Coefficient (°C/°C [†]) | Accessory Error (°C [‡]) |
| | | 10 Hz | 50 Hz | 60 Hz | | |
| 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 | | |

| Thermocouple Type | °C | Error (°C) 15 °C to 35 °C, 1 Year | | | 0 °C to 15 °C, 35 °C to 55 °C | |
|-------------------|-------|--------------------------------------|-------|-------|---|--|
| | | Filter Setting | | | Temperature Coefficient (°C/°C [†]) | Accessory Error (°C [‡]) |
| | | 10 Hz | 50 Hz | 60 Hz | | |
| 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 | | |

* 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.

† Add when the thermocouple accessory and the NI 435x are outside of the 15 °C to 35 °C temperature range.

‡ Add when the thermocouple accessory is outside of the 15 °C to 35 °C temperature range.

RTD Accuracy (with I_{EX} or I_{EX0})*

| RTD | °C | Error (°C) 15 °C to 35 °C, 1 Year | | | 0 °C to 15 °C, 35 °C to 55 °C |
|----------|------|--------------------------------------|-------|-------|---------------------------------------|
| | | Filter Setting | | | Temperature Coefficient (°C/°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 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.

RTD Accuracy (with I_{EX1})*

| RTD | °C | Error (°C) 15 °C to 35 °C, 1 Year | | | 0 °C to 15 °C, 35 °C to 55 °C |
|----------|------|--------------------------------------|-------|-------|---------------------------------------|
| | | Filter Setting | | | Temperature Coefficient (°C/°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 | |

* 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})*

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

* 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.

DC Voltage Accuracy*

| Range (Volts) | % of Reading 15 °C to 35 °C | | | Add μV (with Auto Zero) 15 °C to 35 °C | | | Add μV (without Auto Zero) 15 °C to 35 °C | | | Temperature Coefficient 0 °C to 15 °C, 35 °C to 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 | 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 |

* Voltage specifications do not include errors resulting from common-mode voltages. Calculate additional common-mode voltage errors as: common-mode voltage/10^(CMR specification in db/20).



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 click **KnowledgeBase** under *Option 3*. Enter 1W3E9CHE in the search field to access the entry called *Calculating the Accuracy of a Specific Resistive Sensor*.

Resistance Accuracy (with I_{EX} or I_{EX0})*

| Range (W) | % of Reading 15 °C to 35 °C | | | Add Ω (with Auto Zero) 15 °C to 35 °C | | | Add Ω (without Auto Zero) 15 °C to 35 °C | | | Temperature Coefficient 0 °C to 15 °C, 35 °C to 55 °C % Reading/°C |
|--------------|--------------------------------|--------|--------|--|-------|-------|---|-------|-------|--|
| | | | | Filter Setting | | | Filter Setting | | | |
| | 24 Hour | 90 Day | 1 Year | 10 Hz | 50 Hz | 60 Hz | 10 Hz | 50 Hz | 60 Hz | |
| 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 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 k Ω may require 1 s setting time.

Resistance Accuracy (with I_{EX1})*

| Range (W) | % of Reading 15 °C to 35 °C | | | Add Ω (with Auto Zero) 15 °C to 35 °C | | | Add Ω (without Auto Zero) 15 °C to 35 °C | | | Temperature Coefficient 0 °C to 15 °C, 35 °C to 55 °C % Reading/°C |
|--------------|--------------------------------|--------|--------|--|-------|-------|---|-------|-------|--|
| | | | | Filter Setting | | | Filter Setting | | | |
| | 24 Hour | 90 Day | 1 Year | 10 Hz | 50 Hz | 60 Hz | 10 Hz | 50 Hz | 60 Hz | |
| 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 |

* 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
 $[0.42\text{ °C} + (38\text{ °C to }35\text{ °C}) \times 0.02]$
- 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
 $[0.42\text{ °C} + (38\text{ °C to }35\text{ °C}) \times 0.02 + 0.25\text{ °C}]$
- 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
 $[1\text{ V} \times 0.0101\% + 18\text{ μV}]$
- 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
 $[1\text{ V} \times 0.0101\% + 18\text{ μV} + (38\text{ °C to }35\text{ °C}) \times \{1\text{ V} \times 0.0004\%/^{\circ}\text{C} + 1\text{ μV}/^{\circ}\text{C}\} + (0.5\text{V}/10^{100/20})]$

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±} , I _{EX0±} , I _{EX1±}) | ±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 |
| ±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 μ A |
| Input high current ($V_{in} = 5$ V) | — | 10 μ A |
| 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..... | 3 U, one slot, PXI/cPCI module 2.0 × 13.0 × 21.6 cm (0.8 × 5.1 × 8.5 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 °C to 55 °C

Storage temperature -20 °C to 70 °C

Humidity Up to 80% RH, noncondensing

Maximum altitude 2,000 m

Measurement Category I

Pollution Degree (indoor use only) 2



Caution Do not use for measurements within Categories II, III, or IV.

Safety

◆ PCI/PXI Only

The NI PCI/PXI-435x meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

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



Note For UL and other safety certifications, refer to the product label, or visit ni.com/certification, 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, operate this device with shielded cabling.

CE Compliance

The NI 435x 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/certification, search by model number or product line, and click the appropriate link in the Certification column.

Signal Connections

This section lists the pinouts of the NI 435x.

The TBX-68 accessory is an extension of the connector of the NI 435x device; therefore, the pinout of the screw terminal of the TBX-68 corresponds to the pinout of the NI 435x device.

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 435x (USB, PXI, PCI).

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

| NI 435x (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 |
| CH6- | 26 |
| CH7+ | 25 |

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

| NI 435x (USB, PXI, PCI) Signal Name | TBX-68 Screw Terminal |
|--|----------------------------------|
| 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 |
| I_{EX1+} (NI 4351 only) | 44* |
| I_{EX1-} (NI 4351 only) | 10* |
| DIO0 | 7 |
| DIO1 | 6 |
| DIO2 | 5 |
| DIO3 | 4 |

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

| NI 435x (USB, PXI, PCI) Signal Name | TBX-68 Screw Terminal |
|---|--|
| DIO4 | 37 |
| DIO5 | 3 |
| DIO6 | 2 |
| DIO7 | 1 |
| +5V | 8 [†] |
| 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 |
| <p>* 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.</p> <p>[†] The current available may be limited to less than 50 mA (typical) when using the NI USB-4350.</p> | |



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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 | <i>See</i> 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 $+5\text{ V}$). |
| 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 an NI 435x 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.

virtual channels Channel names that can be defined outside the application and used without having to perform scaling operations.

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