

# **NI Digital Multimeters Help**

June 2008, 370384M-01

This help file provides technical information about National Instruments digital multimeters (DMMs) and NI-DMM driver software.

National Instruments DMMs include the following devices:

DMM	Details
NI PXI-4072	6½ digits; functionality includes inductance and capacitance modes
NI PXI-4071	7½ digits, 1000 V, 3 A with 10 pA sensitivity
NI PXI/PCI-4070	6 <sup>1</sup> / <sub>2</sub> digits
NI PXI/PCI/PCIe/USB- 4065	6½ digits
NI PXI/PCI-4060	5 <sup>1</sup> / <sub>2</sub> digits
NI PCMCIA-4050	5½ digits; for use with portable applications, including laptop computers and personal digital assistants (PDAs)

Refer to <u>Programming with NI-DMM</u> for <u>LabVIEW reference</u>, <u>C/CVI/VB</u> <u>reference</u>, and <u>examples</u> written in National Instruments LabVIEW, LabWindows<sup>™</sup>/CVI<sup>™</sup>, and Microsoft Visual Basic.

For more information about this help file, refer to the following topics:

Using Help

Related Documentation

<u>Glossary</u>

**Important Information** 

Technical Support and Professional Services

To comment on this documentation, refer to the <u>National Instruments</u> <u>Web site</u>.

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# **Related Documentation**

Documentation is available at **Start»All Programs»National** Instruments»NI-DMM»Documentation.

Calibration Procedures	-	Select Manual Calibration Procedures at the <u>NI Calibration</u> Solutions Web site for the most recent version of these documents.
Getting Started Guide	NI Digital Multimeters Getting Started Guide	Refer to the <u>NI Product Manuals</u> <u>Library</u> Web site for the most recent version of these documents.
Readme	NI-DMM Readme File	
Specifications	NI 4050 Specifications NI 4060 Specifications NI 4065 Specifications NI 4070/4072 Specifications NI 4071 Specifications	

# **Using Help**

<u>Conventions</u> <u>Navigating Help</u> <u>Searching Help</u> <u>Printing Help File Topics</u>

# **Fundamentals**

This book explains DMM-specific terms and is divided into the following topics:

- Measurement Quality
- Measurement Considerations

# **Measurement Quality**

To achieve the highest measurement quality, you must understand the relationships between <u>accuracy</u>, <u>sensitivity</u>, <u>resolution</u>, <u>noise</u>, and <u>precision</u>.

### Accuracy

A reading from a DMM can differ from the actual input. **Accuracy** represents the uncertainty of a given measurement and can be defined in terms of the deviation from an ideal transfer function, as follows:

y = mx + b

where

*x* is the input

m is the ideal gain of a system

b is the offset

Applying this example to a DMM signal measurement, y is the reading obtained from the DMM with x as the input, and b is an offset error that you may be able to null before the measurement is performed. If m is 1, the output measurement is equal to the input. If m is 1.000001, then the error from the ideal is 1 ppm or 0.0001%.

The following table shows some ppm to percent conversions.

ppm	Percent
1	0.0001
10	0.001
100	0.01
1,000	0.1
10,000	1

Most high-resolution, high-accuracy DMMs describe accuracy in units of ppm (DC functions) and percentage (AC functions). Therefore, DC and AC accuracy specifications commonly appear as  $\pm(ppm \ of \ reading + ppm \ of \ range)$  or  $\pm(\% \ of \ reading + \% \ of \ range)$ , respectively. The reading component is the deviation from the ideal *m*, and the range component is the deviation from the ideal *b*, which is zero. The *b* errors are most commonly referred to as offset errors.

Hence, accuracy is often expressed as:

(% Reading) + Offset

or

(% Reading) + (% Range)

or

±(ppm of reading + ppm of range)

Note To determine which method is used, refer to the specifications document included with the DMM you are using.

For example, assume a DMM set to the 10 V range is operating 90 days after calibration at 23 °C  $\pm$ 5 °C and is expecting a 7 V signal. The DC accuracy specifications for these conditions state  $\pm$ (20 *ppm of reading* + 6 *ppm of range*). To determine the accuracy of the measurement under these conditions, use the following formula:

Accuracy =  $\pm$ (ppm of reading + ppm of range) =  $\pm$ (20 ppm of 7 V + 6 ppm of 10 V) =  $\pm$ ((7 V(20/1,000,000) + (10 V(6/1,000,000)) =  $\pm$ 200  $\mu$ V

Therefore, the reading should be within  $\pm 200 \ \mu\text{V}$  of the actual input voltage.

Note Temperature can have a significant impact on the accuracy of a DMM and is a common problem for precision measurements. The temperature coefficient, or tempco, expresses the error caused by temperature. Errors are calculated as ±(ppm of reading + ppm of range)/°C or ±(% of reading + % of range)/°C. Refer to Self-Calibration for examples of these calculations.

### Sensitivity

Sensitivity is the smallest unit of a given parameter that can be meaningfully detected with the instrument when used under specified conditions.

For example, assume the sensitivity of a DMM in the volts function is 100 nV. With this sensitivity, the DMM can be used to detect a 100 nV change in the input voltage.

### Resolution

For a <u>noise</u>-free DMM, **resolution** is the smallest change in an input signal that produces, on average, a change in the output signal. Resolution can be expressed in terms of bits, digits, or absolute units, which are related to each other.

#### Bits

Resolution is often expressed in bits, which specifically refers to the performance of the analog-to-digital converter (ADC). Theoretically, a 12-bit ADC can convert an analog input signal into 2<sup>12</sup> (4,096) distinct values. 4,096 is the number of least significant bits (LSB). LSB can be translated into digits of resolution:

Digits of resolution =  $log_{10}$  (Number of LSB)

Using the previous equation, a DMM with a 12-bit ADC has a resolution of:

Log<sub>10</sub> (4,096) = 3.61 digits

 $\overline{\mathbb{N}}$ 

**Note** If a 12-bit ADC is used to digitize signals in a DMM, it might be insufficient to call this DMM a 3½–digit DMM, as noise must also be considered. Noise may reduce the number of LSBs and, therefore, the number of digits.

#### DMM Absolute Units and Digits of Resolution

For traditional DMMs,  $5\frac{1}{2}$  digits refers to the number of digits displayed on the readout of a DMM. A traditional  $5\frac{1}{2}$ -digit DMM has five full digits that only display values from 0 to 9 and one half digit that only displays 0 or 1. This DMM can show positive or negative values from 0 to 100,000.

For more sophisticated digital instruments, and particularly virtual instruments, digits of resolution does not directly apply to the digits displayed by the readout.

### Absolute Units

Counts for a DMM is analogous to LSBs for an ADC. A **count** represents a value that a signal can be digitized to and is equivalent to a step in a quantizer. The weight of a count, or the step size, is the absolute unit of resolution.

```
Absolute unit of resolution = total span/counts
```

#### Digits

Digits can be defined as:

```
Digits of resolution = log_{10} (total span/absolute unit of resolution)
```

For example, a noise–free DMM set to the 10 V range (20 V total span) with 200,000 available counts has an absolute unit of resolution of:

Absolute unit of resolution = 20.0 V/200,000 = 100  $\mu$ V

The readout of this noise–free DMM would display six digits. A change of the last digit would indicate a change of 100  $\mu V$  of the input signal.

An 18-bit ADC provides the minimum number of LSB. You can now calculate the digits of resolution:

 $(2^{17} = 131,072, 2^{18} = 262,144)$ 

Digits of resolution =  $\log_{10} (20.0 \text{ V}/100 \times 10^{-6} \text{ V})$ 

Digits of resolution = 5.3

This noise–free DMM can be called a  $5\frac{1}{2}$  digit DMM.

The quantization process introduces into any converted signal an irremovable error, called the quantization noise. For input signals through a uniform quantizer (without overload distortion), the rms value of the quantization noise in a noise–free DMM can be expressed as:

rms of quantization noise = absolute units of resolution/ $\sqrt{12}$ 

In reality, a noise-free DMM does not exist and you need to account for the noise level when calculating absolute units of resolution. You can define the effective absolute units of resolution of a noisy DMM as the step size of a noise-free DMM with a quantization noise equal to the total noise of the noisy DMM.

Effective absolute units of resolution =  $\sqrt{12}$  \* rms noise

You can define the Effective Number of Digits (ENOD) of this noisy DMM as:

```
ENOD = log<sub>10</sub>(total span/Effective absolute units of resolution)
```

### Example 1

If a DMM set on the 10 V range (20 V total span) shows readings with an rms noise level of 70  $\mu$ V, its effective absolute units of resolution and the ENOD is:

Absolute units of resolution =  $\sqrt{12 * 70 \mu}$  V = 242.49  $\mu$ V

ENOD =  $\log_{10} (20.0 \text{ V}/242.49 \times 10^{-6} \text{ V}) = 4.92 \text{ digits}$ 

This DMM can be called a 5 digit DMM.

The minimum number of counts needed for this DMM would be 20 V/242.49\*10<sup>-6</sup> V = 82,478. The minimum number of bits needed would be 17 ( $2^{16} = 65,536$ ,  $2^{17} = 131,072$ ).

#### Example 2

If the same DMM demonstrates an rms noise level of 20  $\mu$ V:

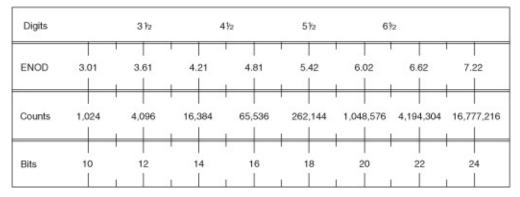
Absolute units of resolution =  $\sqrt{12} * 20 \ \mu\text{V} = 69.28 \ \mu\text{V}$ 

ENOD =  $\log_{10} (20 \text{ V}/69.28 \times 10^{-6} \text{ V}) = 5.46 \text{ digits}$ 

This DMM can be considered a " $5\frac{1}{2}$ " digit DMM.

The minimum number of counts needed for this DMM would be 20 V/69.28\*10<sup>-6</sup> V = 288,675. The minimum number of bits needed would be 19 ( $2^{18} = 262,144, 2^{19} = 524,288$ ).

The following table relates bits, counts, and ENOD to conventional digits of resolution for DMMs. As evidenced by the table, bits, counts, and ENOD are deterministically related. A direct mathematical relationship between ENOD and digits does not exist because digits are used only as an approximation.



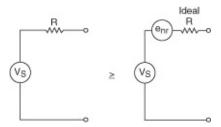
### Noise

Noise in a measurement can originate from the instrument taking the measurement or from an interfering signal passing through the instrument and causing measurement instability. When considering noise, you need to know the measurement bandwidth because it sets the bounds for how you can manage the noise. You can decrease the measurement bandwidth by increasing the <u>aperture</u> of the measurement or by <u>averaging</u> the measurement.

Noise in the system is a common challenge in designing measurement systems. Noise sources in the environment can be electrostatically or inductively coupled in from the powerline; therefore, most DMMs specify noise rejection at line frequencies of 50 Hz or 60 Hz. The rejection at 400 Hz is, at a minimum, as good as the rejection at 50 Hz because the aperture time for 50 Hz also eliminates 400 Hz components. For more information about how to configure the NI 4065 and NI 4070/4071/4072 for optimum normal-mode rejection ratio (NMRR), refer to DC Noise Rejection.

#### Johnson Noise of Resistors

A commonly overlooked source of noise in precision instrumentation is the source noise resistance, as shown in the following figure.



Even a simple fixed-value resistor is noisy. The inherent noise generated by a non-ideal resistor is represented by a noise voltage source  $(e_{nr})$  in series with the ideal, noise-free resistance. This noise results from random motion of thermally generated electrons in the material. This signal is usually called Johnson noise. The Johnson's equation normalized to 1 k $\Omega$  results in the following equation:

 $V_n = 4[\sqrt{(R/1 \text{ k}\Omega)}][(nV/\sqrt{(Hz)})]$ 

$$e_{nr} = \sqrt{4kTRf}$$

This noise, which is present in every resistor at common laboratory

temperatures, is a function of temperature, the value of the resistance, and the bandwidth of the measurement. The noise is defined as:

 $e_{nr} = 1.28 \times 10^{-10} \times \sqrt{(Rf) rms}$ 

You can convert this equation to:

 $e_{nr} = 8.45 * 10^{-10} * \sqrt{(\text{Rf}) p - p}$ 

where

*R* =resistance being measured

f = noise bandwidth of the measurement

This equation assumes you are using ideal resistor elements that exhibit white noise. The white noise is assumed to be a Gaussian distribution. Some resistors, such as certain carbon film resistors, can generate noise from other mechanisms when current is passed through them. Metal foil and wire wound resistors approach this theoretical limit.

As a point of reference to simplify the calculation, a 1 k $\Omega$  resistor has  $4 \, nV/VHz$  rms noise density (1 Hz bandwidth). You can scale this value to get to any noise level given any resistor or frequency by multiplying it by  $\sqrt{(f \times (R/1k))}$ . For example, a 100 k $\Omega$  resistor in a 100 Hz bandwidth has a noise of:

 $e_{nr} = 4 \ nV \sqrt{(Hz)} * \sqrt{(100 * (100 k\Omega / 1 k\Omega))}$ 

 $e_{nr} = 400 nVrms$ 

If the DMM is digitizing at 1 kS/s, the measurement bandwidth is 1 kHz and the effective noise is:

 $e_{nr} = 4 \ nV\sqrt{(Hz)} * \sqrt{(1,000 * (100 k\Omega / 1 k\Omega))}$  $e_{nr} = 4 \ nV \times 316$  $e_{nr} = 1.26 \ \muVrms \ or \ 8.3 \ \mu V_{n-n}$ 

Thus, the source resistance limits the noise floor of the measurement over a 1 kHz bandwidth to 8.3  $\mu$ Vp-p.

### Precision

Precision is a measure of the stability of the DMM and the repeatability of its measurement results for the same input signal. Resolution is a measure of the precision. Precision is given by:

Precision =  $1 - |X_n - Av(X_n)|/|Av(X_n)|$ 

where

 $X_n$  = the value of the *n*th measurement

 $Av(X_n)$  = the average value of the set of *n* measurements

For example, if you are monitoring a constant voltage of 1 V, and your measured value changes by 20  $\mu V$  between measurements, then your measurement precision is:

Precision  $(1 - 20 \mu V/1 V) \times 100 = 99.998\%$ 

Precision is most valuable when you are using the DMM to calibrate a device or perform relative measurements.

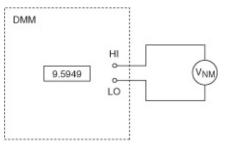
# **Measurement Considerations**

When taking measurements with a DMM, consider the following:

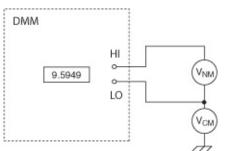
- Normal and common-mode signals
- Normal-mode rejection ratio (NMRR)
- Common-mode rejection ratio (CMRR)
- Effective common-mode rejection ration (ECMRR)
- Input resistance
- Burden voltage
- Thermal voltages
- <u>Settling time</u>
- <u>Resistor self-heating</u>
- Dielectric absorption
- Residual impedance
- Stray admittance

### Normal and Common-Mode Signals

A normal-mode signal is a signal applied differentially to the DMM front panel connectors for the purpose of measuring that signal, as shown in the following figure.



A common-mode signal is the component of an input, "common" to the differential input, as shown in the following figure.



## Normal-Mode Rejection Ratio (NMRR)

Normal-mode rejection ratio (NMRR) describes the ability of the DMM to reject an AC <u>normal-mode signal</u>, usually at powerline frequencies. NMRR is given by the following formula:

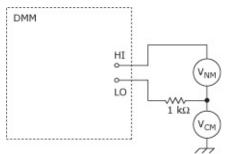
 $NMRR = 20*log(V_{in}/V_{error})$ 

where  $V_{error}$  is the value returned by the DMM for an applied AC normalmode voltage  $V_{in}$ .

NMRR is useful for measurement systems that can eliminate signals at a given frequency or over a range of frequencies. NMRR, which is often used to indicate the capability of the instrument to reject powerline noise of 50 or 60 Hz, is valid only at the specified frequency and is useful when making DC measurements.

# **Common-Mode Rejection Ratio (CMRR)**

Common-mode rejection ratio (CMRR) describes the ability of the DMM to reject a <u>common-mode signal</u> and is often specified with a 1 k $\Omega$  resistance in the LO input lead, as shown in the following figure.



CMRR is important because it indicates how much of the common-mode signal affects your measurement. The CMRR is defined by the following equation:

CMRR = 20\*log<sub>10</sub>(Differential Gain/Common-Mode Gain)

For example, if you are measuring a thermocouple in a noisy environment, the noise from the environment appears on both input leads. Therefore, this noise is a common-mode signal that is rejected by the CMRR of the instrument.

## Effective Common-Mode Rejection Ratio (ECMRR)

Effective common-mode rejection ratio (ECMRR) is the sum of CMRR and NMRR at a given frequency and is only valid for DC measurements. It is the effective rejection on a given noise signal that is applied to both input leads because it is rejected first by the CMRR capability of the instrument and then again by its NMRR capability. This specification is useful at powerline frequencies, particularly for laboratory and manufacturing floor environments. An equivalent equation to represent ECMRR is as follows:

 $ECMRR = 20*log_{10}(V_{CM}/V_{error})$ 

where  $V_{error}$  is the value returned by the DMM in response to an applied common mode voltage  $V_{CM}$ .

For example, if you are measuring 1 mVDC with a DMM that specifies an ECMRR of 130 dB at 60 Hz, and you have a common-mode interference (noise) of 100 mVrms, then the resulting measurement error is:

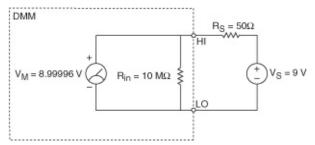
Measurement Error =  $10^{(-130/20)} \times 100 \text{ mV} = 316 \text{ nV}$ 

which is 0.03% of your measured signal instead of the 10,000% error that the 100 mV interference would otherwise imply.

#### **Input Resistance**

Resistance is a measure of the opposition to the flow of current. The input resistance of the DMM can affect the accuracy of voltage measurements, particularly when the resistance of the source voltage is comparable to the input resistance of the DMM.

For example, assume a DMM with a 10 M $\Omega$  input resistance measures a 9 V source voltage with a series resistance of 50  $\Omega$  while in a 10 V DC range, as represented in the following figure.



Using the following formula, you can determine the approximate value returned by the DMM:

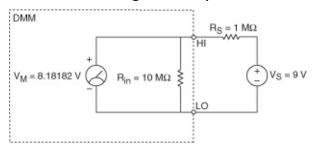
 $V_M = V_S * [(R_{in})/(R_S + R_{in})]$ 

where  $V_M$  is the voltage measured by the DMM,  $V_S$  is source voltage,  $R_{in}$  is the input resistance of the DMM, and  $R_S$  is external source resistance.

$$V_M = (9~V * 10~M~\Omega)/(50~\Omega + 10~M~\Omega)$$

*V<sub>M</sub>* = 8.99996 *V* 

Another example is to assume a DMM with a 10 M $\Omega$  input resistance measures a 9 V source voltage with a series resistance of 1 M  $\Omega$  while in a 10 V DC range, as represented in the following figure.



Using the same formula, you can determine the approximate value returned by the DMM.

$$V_M = (9 V * 10 M \Omega) / (1 M \Omega + 10 M \Omega)$$

*V<sub>M</sub>* = 8.18182 *V* 

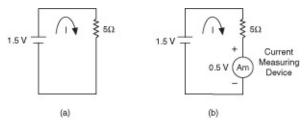
When measuring the source voltage with a low source resistance, the DMM returns a value that was accurate to within  $\pm 0.0005\%$ , or 5 ppm, and the same source voltage with a high resistance returns a value that was accurate to within  $\pm 10\%$ , or 100,000 ppm.

NI 4065 and NI 4070/4071/4072 users can <u>select the input resistance</u> for DC voltage measurements.

## **Burden Voltage**

Burden voltage is the voltage drop caused by current flowing through a current measuring device. A large burden voltage can affect the circuit being measured, corrupting the measurement. For this reason, it is desirable for burden voltage to be kept as low as possible.

The following figure shows a 1.5 V source with a 5  $\Omega$  load. To measure the current on the circuit, an ammeter is connected in series with the circuit. In this figure, the ammeter has a 0.5 V burden voltage.



Without burden voltage (figure a), the calculated current is:

$$I_{actual} = 1.5 V / 5 \Omega$$

 $I_{actual} = 0.3 A$ 

With burden voltage (figure b), the current in this circuit equals:

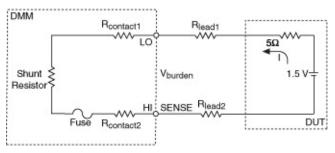
 $I_{measured} = (1.5 V - 0.5 V) / (5 \Omega)$ 

 $I_{measured} = 0.2 A$ 

In the figure above, burden voltage of the current measuring device subtracts from the voltage across the 5  $\Omega$  resistor. The result is a significant error in the measurement. In this case, the error caused by the burden voltage is 33%. Problems like this can easily crop up when using a shunt resistor to measure the current drawn by logic voltages <3.3 V common in today's digital systems.

For the maximum burden voltage per range, refer to <u>Related</u> <u>Documentation</u> for the specifications documents for the DMMs.

A more complete model of the burden voltage in a DMM is shown in the image below. In this model, you can see that the connections between the DUT and the DMM can also introduce an error into the measurement.



The burden voltage listed in the specifications documents takes into account the voltage drop on the resistance of the ammeter shunt plus the contact and fuse resistances. Usually, the specifications of the DMMs list the maximum burden voltages per range. As a general rule, you should take into account the error introduced by burden voltage if the voltage drop on the source impedance and on the connecting leads is comparable to the burden voltage.

Refer to <u>Related Documentation</u> for the *NI 4065 Specifications*, the *NI 4070/4072 Specifications*, and the *NI 4071 Specifications*, which list the burden voltage specifications.

If the source impedance and leads in your system make the error introduced by the burden voltage relevant, then the measured current is equal to the following equation:

$$I (5 \Omega + R_{LEAD1} + R_{LEAD2}) + V_{BURDEN} = 1.5 V$$

 $I_{measured} = (1.5 \text{ V} - \text{V}_{BURDEN}) / (5 \Omega + R_{LEAD1} + R_{LEAD2})$ 

Recall that the DMM specifications documents list the maximum burden voltage per range. However, if you are measuring at less than full scale, then the actual burden voltage is lower. In this case, you can calculate the actual burden voltage according to the following equation:

Actual  $V_{BURDEN} = V_{BURDEN} * (I_{measured} | I_{full scale}),$ 

where I<sub>full scale</sub> corresponds to the current range that you are using

Possible techniques to reduce error caused by ammeter burden voltage include the following:

- When using the current function within the DMM, keep leads to the ammeter short and use the appropriate gauge of cable to minimize voltage drops from leads.
- Sense remotely with external shunts to eliminate the need for long current-carrying cables to the DMM. Use the lowest value of

shunt resistance that the measurement allows.

• Use wires in the circuit under test as resistance shunts. Measure the voltage drop across the wire. Then, use the Offset Compensated Ohms feature to measure the resistance of the wire, and calculate  $I = V_{wire}/R_{oco}$ .



Note The NI 4071 has the lowest voltage burden of the NI 4065 and NI 4070/4071/4072 devices.

# **Thermal Voltages**

Thermal voltages, also known as thermal EMFs, are voltages created by the junction of dissimilar metals when a temperature difference exists between these junctions. The generated voltage increases with temperature. The specific metal-to-metal junctions result in specific temperature coefficients (V/°C) called Seebeck coefficients, which are shown in the following table.

Junction	Seebeck Coefficient (µV/°C)
Copper–Copper	<0.3
Copper–Gold	0.5
Copper–Silver	0.5
Copper–Brass	3
Copper–Nickel	10
Copper–Lead-Tin Solder	1–3
Copper–Aluminum	5
Copper–Kovar	40
Copper–Copper Oxide	1000

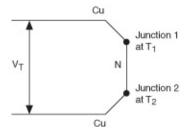
You can determine thermal voltages using the following formula:

$$V_T = K(T_2 - T_1)$$

where

 $T_1$  and  $T_2$  are temperatures measured at the junctions of dissimilar metals

K is the Seebeck coefficient of Copper—N (from table above), and N is a dissimilar metal



To reduce the effects of thermal voltages, use clean copper-to-copper

connectors with gold-plating.



**Note** If you are using National Instruments switch modules and you want to know how thermal EMF and offset voltage affect your measurements, refer to the *Thermal EMF and Offset Voltage* section of the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

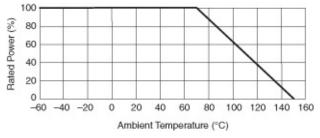
### **Settling Time**

Settling time is the time required for a measurement system to stabilize to a specified accuracy limit. The DMM settling time is dictated by the measurement range, cable properties, source impedance, and change in input level. Use short cables with low dielectric absorption and minimal capacitance—NI recommends Teflon cable. Ideally, your source should have a low output impedance (for example, <10 k $\Omega$ ). Settling time becomes especially important in scanning systems. The scanner or multiplexer requires an additional settling time before the measurement can be taken. NI-DMM allows for a programmable delay between channels so that both the DMM and the multiplexer can settle. Settling times are dependent on the input signal and your selected resolution.

# **Resistor Self-Heating**

As dissipation of power in a resistor increases, the temperature of the resistor increases and causes a change in the resistance value. You can calculate how much error is introduced in your measurement by resistor self-heating from the derating curve of Rated Power(%) vs. Ambient Temperature commonly given in resistor specifications.

The specifications of resistors include a derating curve, similar to the one shown below. Notice that this curve does not show the temperature change of the resistor due to self-heating. The curve shows the percentage of the rated power that you can apply to a resistor vs. the ambient temperature. So at 70 °C of ambient temperature, you can apply up to 100% of the rated power, but at 100 °C you can only apply up to 65% of the rated power. Refer to the following graph.



At any temperature, the resistor will have a temperature change due to self-heating (which we will refer to as  $\Delta T_{SH}$  from here on), so the actual temperature of the resistor is the ambient temperature plus an unknown  $\Delta T_{SH}$ . Even though this graph is not directly showing the value of  $\Delta T_{SH}$ , it can be calculated from the graph.

Notice that at 70 °C and applying 100% of the rated power, the temperature of the resistor will be equal to 70 °C plus  $\Delta T_{SH}$ . At 150 °C, you cannot apply any power to the resistor, so the temperature of the resistor is equal to the ambient temperature. You can thus infer that when applying 100% of the rated power at 70 °C the total temperature of the resistor is 150 °C. Therefore, above 70 °C, the value of  $\Delta T_{SH}$  increases in such a way that when you add to it the ambient temperature it surpasses 150 °C. Therefore, you need to limit the power you apply to the resistor to keep the total temperature of the part under 150 °C. Hence, the value of  $\Delta T_{SH}$  is a function of the power applied to the part.

The thermal resistance (a) is therefore equal to the absolute value of the

slope between the 70  $^{\circ}\text{C}$  and the 150  $^{\circ}\text{C}$  points in the derating curve shown above.

 $\theta = (150 \text{ °C}-70 \text{ °C})/\Delta P = (150 \text{ °C}-70 \text{ °C})/P_{max}) \text{ °C/W}$ 

If the resistor has a Rated Power at 70  $^\circ\text{C}$  equal to 0.25 W, then the value for  $_\theta$  would be equal to:

θ = (150 °C—70 °C)/ΔP = (150 °C—70 °C)/250 mW = 80 °C/(250\*10<sup>-</sup> <sup>3</sup> W) = 320 °C/W = 0.32 °C/mW

If you want to decrease the thermal resistance, you would need to look for a resistor with higher rated power, or find a way to "heat sink" the resistor to the environment. This however can become complicated and expensive unless the resistor is specifically designed for heat sinking.

You can now calculate the change in temperature due to power dissipation using the thermal resistance (a) and the power on the resistor (product of voltage and current). Then you can use the temperature coefficient of the resistor (usually given in ppm/ °C) to calculate the change in the resistance value.

Resistor self-heating is more relevant when measuring currents above 100 mA. Resistor self-heating does not present a problem on the NI 4065 and NI 4070/4071/4072, because the internal shunt values are selected for optimum performance. You may observe a settling tail of a few ppm of reading due to self-heating when measuring currents over 100 mA; if this is an issue, increase the <u>settling time</u> of your measurement.

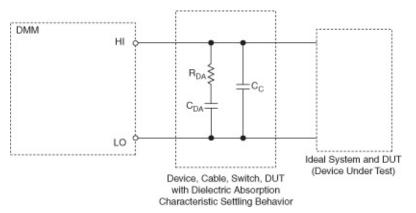
### **Dielectric Absorption**

Dielectric absorption caused by cable materials can increase settling time. The figure below illustrates dielectric absorption due to cable resistance and dielectric polarization capacitance where:

 $R_{DA}$  = Insulation resistance of cabling (10 G $\Omega$ -10<sup>14</sup> $\Omega$ )

 $C_{DA}$  = Dielectric polarization capacitance (0.1–1 pF/ft)

 $C_C$  = Cable capacitance (10–40 pF/ft)



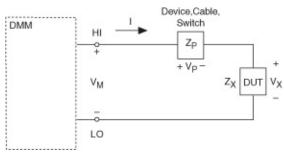
The RC formed by  $R_{DA}$  and  $C_{DA}$  results in slow settle tails that significantly lengthen settling time.

The best way to avoid dielectric absorption effects is to use a high-quality cable, such as Belden 83317E available. Refer to the Belden CDT Incorporated Web site at <a href="https://www.belden.com">www.belden.com</a> for information about this cable.

NI recommends cables with Teflon, polypropylene, or polyethylene insulation. For more information about cabling requirements, refer to <u>Interconnects and Cables</u>.

# **Residual Impedance**

For the NI 4072 only, **Impedance** is a measure of opposition to the flow of alternating currents. **Residual impedances**, which are found in series between the DMM and the DUT, result from the connectivity required between the DMM and the DUT. The residual impedance on the test application introduces an error by dividing the voltage across the DUT. This error can affect the accuracy for inductance and capacitance measurements, particularly when the residual impedance is comparable to the impedance of the DUT. The following figure illustrates residual impedance in a typical measurement.



where

 $Z_P$  = residual impedance

 $Z_x$  = impedance of the DUT

 $V_M$  = total input voltage measured by the DMM

 $V_P$  = voltage drop across total residual impedance

 $V_X$  = voltage across DUT

 $V_M = V_P + V_X$ 

 $Z_M = V_M / I = V_P / I + V_X / I = Z_P + Z_X$ 

Note Bold values denote vector quantities or complex numbers.

For example, in an application with a 10 uH inductor in series with a 1 uH cable, the meter reads a 10% error, or 11 uH (10 uH + 1 uH).

To reduce residual impedances on test fixtures and cables, take the following steps:

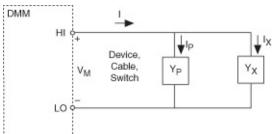
- Keep the cables as short as possible.
- Avoid any variations due to mechanical vibrations, handling, and temperature changes.
- Use the compensation techniques available on the NI 4072.

Refer to **OPEN/SHORT Compensation** for more information.

In addition to residual impedance, stray admittances can also be found in test setups. Refer to <u>Stray Admittance</u> for more information.

# **Stray Admittance**

For the NI 4072 only, **Admittance** is the reciprocal of the residual impedance. **Stray admittances**, which are found in series between the DMM and the DUT, result from the connectivity required between the DMM and the DUT. The stray admittance on the test setup introduces an error on the voltage reading by dividing the excitation current. This error can affect the accuracy of inductance and capacitance measurements, particularly when it is comparable to the admittance of the DUT. The following figure illustrates stray admittance in a typical measurement:



where

M

 $V_M$  = total input voltage measured by the DMM

**Y**<sub>P</sub> = stray admittance

 $Y_X$  = admittance of the DUT

*I* = test current

 $I_P$  = current going through the stray admittance

 $I_X$  = current going through the DUT

$$I = I_P + I_X$$
$$V_{12} = I/(Y_P + Y_Y)$$

$$Y_M = I/V_M = Y_P + Y_X$$

**Note** Bold values denote vector quantities or complex numbers.

For example, in an application with a 10 nF capacitor in parallel with 1 nF of stray capacitance, the meter reads a 10% error, or 11 nF (10 nF + 1 nF).

To reduce stray admittances on test fixture and cables, take the following steps:

- Keep the cables as short as possible.
- Avoid any variations due to mechanical vibrations, handling, and

temperature changes.

• Use the compensation techniques available on the NI 4072. Refer to <u>OPEN/SHORT Compensation</u> for more information.

In addition to stray admittance, residual impedance can also be found in test setups. Refer to <u>Residual Impedance</u> for more information.

# **Devices**

This section includes the device-specific information for the <u>NI 4072</u>, <u>NI 4071</u>, <u>NI 4070</u>, <u>NI 4065</u>, <u>NI 4060</u>, and <u>NI 4050</u>.

## NI 4072

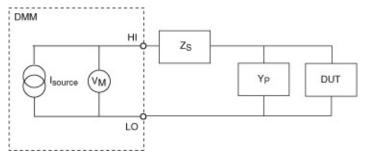
The NI 4072 is a 6½ digit DMM for the PXI bus. The NI 4072 can take <u>capacitance and inductance</u> measurements and can acquire waveforms at 1.8 MS/s. For more information about the NI 4072 specifications, refer to <u>Related Documentation</u> for the NI 4072 specifications document.

This topic contains the following subsections:

- Impedance
- Interconnects and Cables
- **Operation**
- Replacing the Fuse
- Calibrating the NI 4072

#### Impedance

The NI 4072 uses a 2-wire, AC-current technique to measure capacitance and inductance. A current source ( $I_{src}$ ) is supplied to the device under test (DUT), and the NI 4072 determines the measured voltage ( $V_m$ ), as shown in the following figure.



With a known current and voltage, the NI 4072 determines the capacitance or inductance of the DUT if the residual serial impedance  $(Z_s)$  and the stray parallel impedance  $(Y_p)$  are small or negligible compared to the DUT. If  $(Z_s)$  and  $(Y_p)$  introduce a significant error into the measurement, the NI 4072 can measure the error and reduce it using compensation techniques. For more information, refer to the OPEN/SHORT Compensation section.

For the measurement ranges for the capacitance and inductance modes on the NI 4072, refer to <u>Related Documentation</u> for the NI 4072 specifications document.

#### **Interconnects and Cables**

The front of the NI 4072 module has five connectors—four banana plug connectors and one 9-pin mini–circular DIN connector. The four banana plug connectors are high-voltage, safety-agency approved signal connectors. The 9-pin DIN connector labeled AUX I/O is a digital signal connector, which carries triggers and SCXI communication signals. For an illustration of the front panel connectors and wiring instructions, refer to <u>Front Panel Connections</u> topic for the NI 4072.

The input connectors on the NI 4072 are gold-plated, low-thermal copper for best low-voltage performance. The insulator material is a Lexan compound, optimized for low leakage over the full environmental operating range.

For use with the NI 4072, NI recommends selecting a cable with characteristics similar to the Belden 83317E, which is available at <u>www.belden.com</u>. Tape-wrapped polytetrafluoroethylene (PTFE) insulation guarantees low leakage. Copper conductors with silver plating perform very well for low-voltage measurements because of their low thermal characteristics. Use a cable with at least 90% shielding effectiveness.

Type of Insulator	AWG	Conductor Material	Resistance per Foot	Capacitance per Foot
TFE	26	Silver-plated copper, stranded	39 mΩ	35.5 pF

Belden #83317E Teflon Insulated Cable

### Operation

The NI 4072 can operate as a DMM and can <u>acquire waveforms</u> up to 1.8 MS/s. The following table lists the functions and ranges supported by the NI 4072 while in DMM mode.

DMM Function	Ranges		
DC Voltage	100 mV, 1 V, 10 V, 100 V, 300 V		
AC Voltage	50 mV, 500 mV, 5 V, 50 V, 300 V		
DC Current*	20 mA, 200 mA, 1 A		
AC Current*	10 mA, 100 mA, 1 A		
2-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ, 10 MΩ, 100 MΩ		
4-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ, 10 MΩ		
Diode	10 V at 1 μA / 10μA / 100μA; 4.5 V at 1 mA		
Frequency/Period	50 mV, 500 mV, 5 V, 50 V, 300 V		
Capacitance	300 pF, 1 nF, 10 nF, 100 nF, 1 μF, 10 μF, 100 μF, 1,000 μF, 10,000 μF		
Inductance	10 uH, 100 uH, 1 mH, 10 mH, 100 mH, 1 H, 5 H		
	* To measure current outside of the normal range on the NI 4072, you must use a current shunt module (CSM). Refer to <u>Measuring Current</u> for more information.		

The following table lists the functions and ranges supported for waveform acquisitions:

Waveform Function	Ranges	Coupling		
Voltage Waveform	100 mV, 1 V, 10 V, 100 V, 300 V	AC or DC		
Current Waveform*	20 mA, 200 mA, 1 A	DC		
* To measure ourrent outside of the normal range on the NII 4072, you must use a ourrent chunt				

\* To measure current outside of the normal range on the NI 4072, you must use a current shunt module (CSM). Refer to the <u>Measuring Current</u> section for more information.

#### **Additional Features**

- <u>Self-Calibration</u>
- Auto Zero
- <u>Configuring Auto Range</u>

- <u>Offset Compensated Ohms</u>
- ADC Calibration
- Input Resistance
- <u>Configuring Measurement Timing</u>
- Aperture Time
- DC Noise Rejection
- <u>Waveform Acquisitions</u>
- Single Point Acquisitions
- <u>Generating Measurement Complete</u>
- <u>Scanning Switch Modules</u>

#### **Replacing the Fuse**

The NI 4072 is equipped with a F 1.25 A 250 V Fast–Acting fuse designed to help protect the DMM and your test system. For instructions on replacing the fuse, refer to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

### Calibrating the NI 4072

Calibration maximizes the accuracy of a DMM. To ensure accuracy, you must perform calibration. NI recommends that you externally calibrate every two years. Refer to the *NI 4070/4072 6½ Digit FlexDMM Calibration Procedure* at the <u>NI Calibration Solutions</u> Web site for information on externally calibrating the NI PXI/PCI-4070/4072. For information on calibrating the NI 4072 using National Instruments Calibration Executive, refer to the <u>NI Calibration Solutions</u> Web site. All NI measurement devices receive NIST-traceable calibration before shipping.

# **Self-Calibration**

Every measurement instrument performs within its specifications over a finite temperature range and time. If the excursions in temperature and time exceed those specified, and you need performance close to the specifications, then you must recalibrate the instrument at the new temperature or after a certain amount of time. The NI 4070/4071/4072 has a <u>self-calibration</u> function that allows you to perform a calibration at the temperature you are making your measurements.

Self-calibration fully recalibrates all functions for DC volts and resistance.

Note <u>niDMM Self Cal</u> and <u>niDMM\_SelfCal</u> reconfigure the DMM without caching the previous configuration. When you attempt to read after self-calibration completes, you receive an error for an invalid function for the current operation mode for reading a waveform, a timeout error for multiple point acquisitions, and a read error for using the incorrect mode for single point acquisitions.

Self-calibration makes the NI 4070/4071/4072 highly accurate and very stable at any operating temperature—well outside of the traditional 18 °C to 28 °C range.

The typical way of expressing accuracy is:

```
Accuracy = ±(X ppm of reading + Y ppm of range)
```

For example, if the last calibration (self or external) was performed at 23  $^{\circ}$ C, and you are using the 10 V range on the NI 4070/4072 and applying a 5 V signal within 18  $^{\circ}$ C to 28  $^{\circ}$ C, the 2–year accuracy is:

2–year Accuracy =  $\pm$ (25 ppm of 5 V + 6 ppm of 10 V) =  $\pm$ 185  $\mu$ V (uncertainty)

This traditional calculation method can cause errors if the temperature is not tightly controlled. When a system is built of multiple traditional instrument components integrated together, the instruments are subject to temperature rises caused by inherent compromises in air circulation and other factors.

If the ambient temperature is outside of the 18 °C to 28 °C range, to calculate the measurement accuracy, you need to calibrate your instrument at the ambient temperature, or add temperature coefficient accuracy for each additional degree outside the calibration range.

Using the NI 4070/4072, assume the ambient temperature is 38 °C. The temperature coefficient (tempco) without self-calibration is:

Tempco = (1 ppm of reading +1 ppm of range)/°C

The 2–year accuracy at 38 °C becomes:

 $\pm$ [25 ppm of 5 V + 6 ppm of 10 V] + [(1 ppm of 5 V + 1 ppm of 10 V) x 10] =  $\pm$ 335  $\mu$ V (uncertainty)

Externally recalibrating a system can be difficult and expensive and as a result generally is performed infrequently.

The NI 4070/4071/4072 incorporates a proprietary self-calibration function for DCV and resistance. This function is unique to the NI 4070/4071/4072 in the following ways:

- Self-calibration corrects for all DCV gain and offset errors within the DMM using a precision, high-stability internal voltage reference, which has an outstanding temperature coefficient and time drift.
- Self-calibration also accounts for all resistance, source, and gain errors.
- In resistance, all errors are corrected to a single internal 10 k $\Omega$  aerospace grade, high-stability foil resistor, which is stable to within 0.8 ppm/°C over the full operating range.

After performing self-calibration at 38 °C, you do *not* need to add any uncertainty to account for temperature change.

The 2-year accuracy after self-calibration at 38 °C becomes:

 $\pm$ (25 ppm of 5 V + 6 ppm of 10 V) =  $\pm$ 185  $\mu$ V (uncertainty)

Note ADC calibration adjusts the drift of the ADC only. While the ADC is the largest drift component of a DMM, other minor, second-order factors exist, such as resistance current sources and signal conditioning gain stages. Self-calibration fully corrects these factors, including the ADC. The following table lists your calibration choices and when to use them:

Calibration Option		When	
Factory calibration	<ul><li> All functions</li><li> Recalibrates for time</li></ul>	Every two years	

	<ul><li>drift of onboard references</li><li>Corrects for AC flatness</li></ul>	
Self- calibration	<ul> <li>Recalibrates the measurement path and ADC for DC volts and resistance</li> </ul>	Every 90 days or when the temperature changes more than 5 °C from last self- calibration
ADC calibration	<ul> <li>Recalibrates ADC drift for all functions</li> </ul>	Every reading when selected
NONE	<ul> <li>Add to all specification 50 ppm of reading every 90 days and 3 ppm of reading/°C typical</li> </ul>	Extended high-speed acquisitions

The NI 4070/4071/4072 incorporates a temperature sensor that can be read to determine when the temperature exceeds 5 °C from the previous calibration. In addition, the previous self-calibration time and date can also be read. For maximum accuracy, NI recommends self-calibrating once every 24 hours or when the temperature changes by more than  $\pm$ 1 °C on the NI 4071 and more than  $\pm$ 5 °C on the NI 4070/4072. Otherwise, NI recommends running self-calibration every 90 days. NI does *not* recommend running self-calibration more than once a day.

During self-calibration, the internal circuitry is automatically disconnected from the input. Therefore, for the majority of applications, users do *not* need to disconnect the input signals during self-calibration. However, excessive signal levels (>30 VDC, >30 VAC<sub>rms</sub>, >20 kHz) at the input terminals of the NI 4070/4071/4072 generate a self-calibration error. Disconnecting the input signals during a self-calibration prevents the error from occurring. If you are using the NI 4070/4071/4072 as part of a switching system, you can open (disconnect) the connections to the NI 4070/4071/4072 input terminals, switch to a non-connected path, or switch to a low voltage, low frequency path. For optimum reliability, avoid application of current to the Amps terminals or signals of >30 V to the Volts Input terminals during self-calibration.

## **Front Panel Connections**

Move the mouse over the text to view the wiring diagrams for the NI 4072, and click for additional information.

**Capacitance** 

Inductance

DC Voltage

AC Voltage

DC Current

AC Current

2-Wire Resistance

4-Wire Resistance

Voltage Drop Across a Diode

**Frequency/Period** 

Voltage Waveform

Current Waveform



SCXI Communication

Triggering

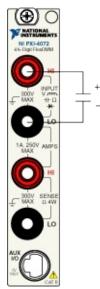
Temperature (Thermocouple)

Temperature (2-wire RTD)

Temperature (4-wire RTD)

Temperature (Thermistor)

# Capacitance

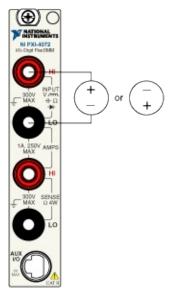


## Inductance

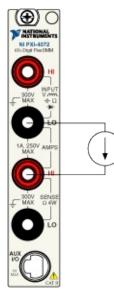
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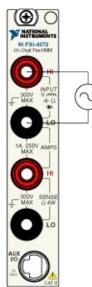
## **DC Voltage**



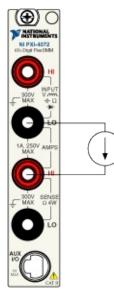
### **AC Current**



## AC Voltage

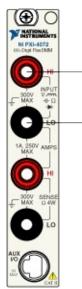


### **DC Current**

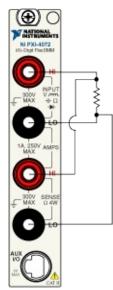


## **2-Wire Resistance**

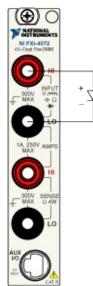
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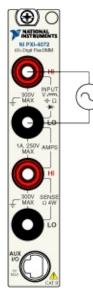
### **4-Wire Resistance**



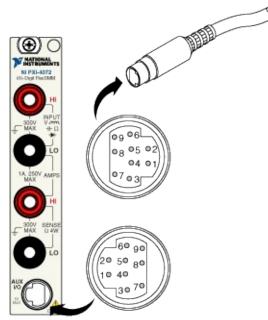
## Voltage Drop Across a Diode



# **Frequency/Period**



# **SCXI** Communication



The following table shows the pins used for SCXI communication:

Pin	Assignment
1–5, 7–9	SCXI Communication

#### **Cable Accessory**

Note When certain NI-PXI 407x devices are installed in the rightmost slot of a PXI/SCXI combination chassis, they can control the SCXI portion of the chassis, and no cable is needed. Refer to <u>PXI</u> <u>Express Compatibility</u> and <u>Scanning Switch Modules</u> for more information.

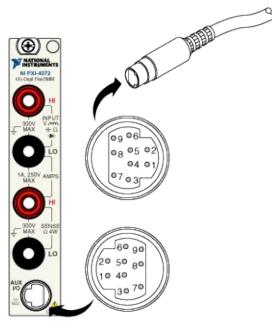
1110		
Jan Start St	- Aller	

This SH9MD-AUX cable allows the NI 4070/4071/4072 to communicate with SCXI switches. Refer to <u>Scanning Switch Modules</u> for more information.

For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

# Triggering



The following table shows the pins used for input and output triggers, which are used during synchronous scanning or handshaking:

Pin	Assignment
2	Ground
3	AUX Trigger In
6	Measurement Complete (MC)
9	External Trigger In (Trigger/Sample Trigger)

#### **Cable Accessories**

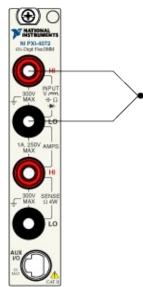
Note When certain NI-PXI 407x devices are installed in the rightmost slot of a PXI/SCXI combination chassis, they can exchange measurement complete (MC) and the input trigger through the backplane, and no cable is needed. Refer to <u>PXI Express</u> <u>Compatibility</u> and <u>Scanning Switch Modules</u> for more information.

AUX Trigger Cable	This cable allows the NI 4070/4071/4072 to trigger
	NI switches, third-party switches, and any other external device during synchronous scanning or handshaking scanning.
	Note The AUX Trigger Cable only provides access to AUX I/O Connector Pins 2, 6, and 9, where Pin 2 is Ground and is present in both ends of the cable.
SH9MD- AUX Cable	This cable allows the NI 4070/4071/4072 to control SCXI switches, send measurement complete (MC), and receive external trigger. This functionality allows the NI 4070/4071/4072 to work under both synchronous scanning and handshaking scanning. Refer to Scanning Switch Modules for more information.

For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

# **Temperature (Thermocouple)**



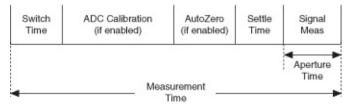
## **DMM Measurements**

The following sections cover optimizing your measurements on the NI 4070/4071/4072.

- DMM Measurement Cycle
- DMM Measurement Defaults
- Capacitance/Inductance (NI 4072 only)
- DC Voltage
- <u>AC Voltage</u>
- DC and AC Current
- <u>Resistance</u>
- Frequency/Period
- <u>Diode</u>

## NI 4070/4071/4072 DMM Measurement Cycle

The NI 4070/4071/4072 measurement cycle is made up of several measurement phases: switch time, settling time, signal measurement phase, Auto Zero, and ADC calibration. Refer to the figure below for relative timing of these phases. The length of the signal measurement phase is set by the aperture time. Generally the settle and aperture times are selected by the device driver based on the specified resolution. These values can also be independently controlled. Refer to <u>Configuring Measurement Timing</u> for more information.



The internal switch time is required to configure the analog circuitry of the NI 4070/4071/4072 for the next measurement, and default settling times precede both ADC calibration and Auto Zero. All of these times are not user programmable.

During resistance measurements, the signal is measured with an applied current source. When Offset Compensated Ohms is enabled, a settle phase and current source OFF measurement phase occurs in place of the Auto Zero phase depicted above.

The AC measurement cycle contains the same phases, but the minimum signal measurement time is based on the minimum frequency required of the measurement. For example, for a minimum frequency of 50 Hz, an aperture of 4x the period of the 50 Hz signal is required, or in this example, 80 ms.

When Auto Range is selected, the Auto Range measurement phase occurs before the Auto Zero and signal measurement phases. After the correct range is identified, the Auto Zero and signal measurements use the selected range.

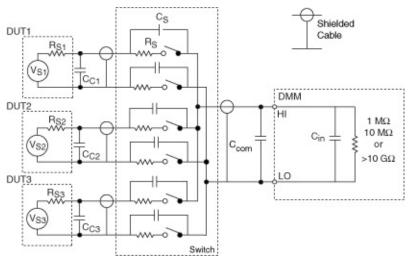


**Note** When using Auto Range, keep in mind that longer apertures significantly slow down Auto Ranging because multiple measurements are made to find the best range possible. For best measurement speed, manually select the desired range.

### **Settling Time**

Prior to every measurement phase, a settling time exists. Refer to DMM <u>Measurement Defaults</u> for the default settling times for each function of the NI 4070/4071/4072. Refer to DMM Measurement Defaults for the default settling times for each function of the NI 4065.

You can modify these values to be longer or shorter. The following figure shows a DMM connected to three devices under test (DUTs) through a multiplexing switch:



Whenever the external switch changes channels, the DMM input is connected to a different voltage or resistance. Each time this process happens, the DMM, interacting with the source, behaves as an RC circuit with a settling time that corresponds to:

ST = kRC

where

R = equivalent resistance of the source

C = the equivalent input capacitance seen by the DMM (C  $_{COM}$  + C  $_{CX}$  + C $_{IN}$ ), where  $C_{CX} = C_{C1}$  or  $C_{C2}$  or  $C_{C3}$  (cable capacitances) depending on the channel selected

k = value related to accuracy required, as shown in the following table; increases as required accuracy increases

*ST* = settling time required

Note NI does not generally recommend scanning currents directly.

The optimum method for scanning currents is to embed shunt resistances in the test system, then scan voltage. Refer to <u>Load</u> <u>Switching</u> for more information.

k	Error	Required Resolution (for full range step)
3	4.98%	
4	1.83%	—
5	0.674%	
6	0.248%	_
7	0.091%	_
8	0.033%	3 <sup>1</sup> / <sub>2</sub> digits
9	0.012%	
10	0.0045%	4 <sup>1</sup> / <sub>2</sub> digits
11	0.0017%	
12	0.00061%	5½ digits
13	0.00023%	—
14	0.000083%	6 <sup>1</sup> ⁄ <sub>2</sub> digits
15	0.000031%	—
16	0.000011%	7 digits
17	0.000004%	7½ digits

Adjusting the default settling time may be important when you are measuring or scanning resistances with values above 10 k $\Omega$ , when C >500 pF, and when speed is of the utmost importance. For the input capacitance of the DMM, refer to <u>Related Documentation</u> for the specifications document. The cable capacitance can be significantly more than the input capacitance. Cable material <u>dielectric absorption</u> complicates the settling time issue.

When switching to the next measurement, consider the following example. Assume a 10 V step occurs on the 10 V range with a required resolution of 6½ digits. Referring to the previous table for 6½ digit settling, k = 14 is required. Consider next a 10 mV step on the 10 V range. The step, being 0.1% of range (10 mV/10 V = 0.1%), can only be observed to 0.1% beyond that (assuming a 6½ digit resolution). In this example, the maximum time required from the previous table corresponds to k = 7, which yields 0.091%. If the difference between channels is known to never exceed 10 mV, then you can save considerable settling time. If you cannot predict what the values are from channel to channel, consider the accuracy required in the measurement. Then assume a step size equal to the full range to identify *k*.

The analysis in the previous example is for fixed range operation. You can select Auto Range for the measurement, but additional delays occur as the DMM seeks the appropriate range for the measurement. NI does *not* recommend Auto Range for optimum speed.

### **Aperture Time**

Aperture time is the period during which the ADC is reading the input signal. Resolution, measurement speed, and frequency rejection are functions of the aperture time. The larger the aperture time, the better the resolution. Select short aperture times for faster measurement speed. You can specify aperture time either in seconds or in power line cycles (PLCs).

The table below lists the default conditions for aperture along with other conditions related to the measurement cycle. These defaults optimize the DMM performance to its specified accuracy.

Function	Default Aperture				
Function	NI 4065	NI 4070	NI 4071	NI	
DC 7½ digits		_	100 ms with <u>Number of</u> <u>Averages</u> = 4		
DC 6½ digits	200 ms	100 ms	100 ms	100 ms	
DC 5½ digits	3.33 ms	500 µs	500 μs¹	500 µs	
DC 4 <sup>1</sup> /2 digits	333 µs	20 µs	50 μs	20 µs	
DC Auto Range	3.33 ms	500 µs	500 µs	500 µs	
AC	<ul> <li>AC 6½ digits — 1 sec</li> <li>AC 5½ digits — Max (100 msec or (10/(minFreq)))</li> <li>AC 4½ digits — Max (10 msec or (5/(minFreq)))</li> </ul>	Max (DC or 4/(minFreq))	Max (DC or 4/(minFreq))	Max (DC 4/(minFr	
AC Auto	Max (100 ms or	Max (500	Max (500 µs	Max (50	

Range	10/(minFreq))	μs or 4/(minFreq))	or 4/(minFreq))	4/(minFr
Frequency	—	2/(minFreq)	2/(minFreq)	2/(minFr
Period		2 x (the maximum period)	2 x (the maximum period)	2 x (the period)
Capacitance and Inductance				•   (   1 •   2 ( 2 1 ( 2 1
<sup>1</sup> For the NI 4	071, on the 5.5 DCV 10	0V range, use	e 1.6 ms.	

By default, the aperture time for a measurement is chosen by the driver based on the configured measurement and resolution. These values are chosen to ensure accuracy for 6½ digit measurements while not sacrificing performance at lower resolutions. For AC, excluding Auto Range, the aperture is expressed as Max (DC or 4/minFreq) for the NI 4070/4071/4072 and 1 sec for the NI 4065. MinFreq, or minimum frequency, is a user-programmable parameter with a default value of 20 Hz.

The same applies for other user selectable values of minFreq.

For example, on the NI 4070/4071/4072, if a minFreq of 1 kHz is selected, then 4/minFreq = 4/1 kHz = 4 ms. In this case, 4 ms would be used as the AC aperture for resolutions <6 digits. For resolutions >6 digits, 100 ms would be used in this example.

For example, on the NI 4065, if a minFreq of 100 Hz is selected, then 5/minFreq = 5/100 Hz = 50 ms. In this case, 50 ms would be used as the AC aperture for 4.5 digits. For 5.5 digits, 10/minFreq = 10/100 Hz = 100 ms would be used in this example. For resolutions >6 digits, 1 sec would be used in this example.

For settling time defaults, refer to <u>Settling Time</u>.

#### Number of Averages for DC Measurements

This function is specific for high-resolution DC measurements.

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**Note** When taking averages of inductance or capacitance measurements, refer to <u>Number of LC Measurements to Average</u>.

If your application requires a long aperture time (>100 ms) it is recommended that Auto Zero is enabled. The offset present may actually drift during the measurement, so that the stored Auto Zero value is invalid by the time the measurement completes. To compensate for this drift, several shorter measurements can be taken with a new Auto Zero offset applied to each measurement. These measurements can then be <u>averaged</u> together by the DMM so that a single value is returned.

To configure an averaged measurement, set the Number of Averages property. For example, if you desire a 500 ms measurement aperture, you can set the aperture to 50 ms and set Number of Averages to 10. Auto Zero must be enabled when the Number of Averages property is greater than one. The DMM will take ten 50 ms measurements each with <u>Auto Zero</u> and return a single measurement.

Note (NI 4071 only) NI-DMM breaks up large aperture times (greater than 6 PLCs) in DC modes (DC voltage, DC current, 2wire resistance, 4-wire resistance, and diode modes) into blocks of 6 PLCs and averages the resulting measurements. For example, if you request an aperture time of 30 PLCs, NI-DMM averages five readings of 6 PLCs. If you do not want to subdivide a long aperture time, you can override this behavior by explicitly setting <u>Number of Averages</u> to 1. Specifying a value >1 for <u>Number of Averages</u> causes NI-DMM to behave exactly as requested without subdividing the aperture time.

#### **ADC Calibration**

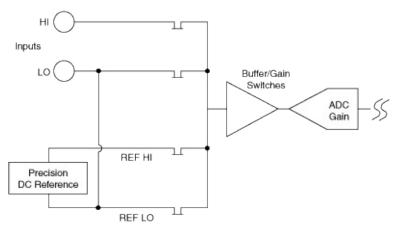
ADC calibration, a method used to compensate for an internal DMM gain error, is a feature exclusive to the NI 4070/4071/4072 DMM that allows you to appropriately trade off measurement speed for long-term accuracy. The NI 4070/4071/4072 ADC is designed for precision, linearity, and stability. By doing routine calibration of the ADC back to a single well-controlled component, you can ensure absolute accuracy of the conversion.

In DCV and resistance at 6½ or 7½ digit resolutions, NI recommends using ADC calibration for the greatest accuracy. In ACV and current, or at resolutions of 4½–5½ digits, ADC calibration is not required for satisfactory performance. When ADC calibration is enabled, every measurement cycle includes an additional phase for acquiring the value of the high-precision reference. This phase yields the most exacting precision because any ADC gain drift is normalized to the input signal, and the ADC gain drift is removed in the resulting mathematical calculation on every measurement.

Traditional methods disperse these measurements over time compromising performance, speed, and deterministic timing. For optimum drift performance, NI recommends using ADC calibration as part of each measurement cycle.

Your application may demand speed over accuracy. In these instances, you can disable ADC calibration.

The following figure represents the process of the ADC calibration cycle. During this cycle, the input is disconnected from the ADC and the precision DC reference is measured. This measurement consists of an ADC calibration Auto Zero (*REF LO*) and an ADC calibration HI (*REF HI*). The normalized value of the reference voltage is calculated from  $V_{ref}$  = *REF HI–REF LO*.



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With ADC calibration disabled, the measurement speed increases by a factor of up to two and you need to add a temperature coefficient error of 3 ppm/°C to the appropriate range specification. Although the error is small, you should still consider the effects. Long-term drift typically degrades by 50 ppm/3 month. If you need to turn off ADC calibration, as you might when you want optimum speed in 6½ or 7½ digit resolution, you can recover to specified accuracy by running periodic self-calibration operations.

**Note** NI recommends that you run self-calibration before taking a 6½ or 7½ digit measurement with ADC calibration disabled.

The measurement effect of ADC calibration decreases as your selected digits of resolution decreases.

### Auto Zero

Auto Zero is a method used to compensate for internal DMM offsets.

Notes The NI 4050 does *not* support Auto Zero.

For NI 4065 devices, Auto Zero is always ON. Auto Zero is an integral part of the signal measurement phase and adds no extra time to the overall measurement.

When Auto Zero is enabled, the internal DMM input is connected to its input LO and measured. The subsequent input signal is measured, and the Auto Zero value subtracted from it. Thus, any offsets in the measurement path or ADC are subtracted from the signal, correcting for the offsets. You can disable Auto Zero before initiating or reading a measurement; it remains disabled until you enable it again.

When you disable Auto Zero, the DMM restores the Auto Zero value from the previous calibration, either <u>self-calibration</u> or external calibration.

If you find the offset to be unacceptable, you can either subtract it algorithmically in a later process, such as by shorting the inputs and recording it, or you can run self-calibration, which calculates and stores new Auto Zero offsets. To maintain stable offset performance in high resolution modes (for example,  $6\frac{1}{2}$  or  $7\frac{1}{2}$  digit resolution) you should enable Auto Zero.

You can also <u>enable Auto Zero</u> ONCE. Auto Zero ONCE performs an Auto Zero and stores the value for use in subsequent measurements, as long as Auto Zero ONCE remains selected. If you disable Auto Zero ONCE, the DMM restores the Auto Zero offset from the previous calibration.

Note The NI 4060/4065 does *not* support setting Auto Zero to ONCE.

NI recommends using Auto Zero ONCE only for multiple measurements taken on the same range. If you enable Auto Zero ONCE for an Auto Range measurement, Auto Zero on is used to ensure that the correct Auto Zero value is applied to each range.

### Overrange/Underrange

This section describes the overrange and/or underrange conditions, as applicable, for each National Instruments DMM.

### NI 4070/4071/4072

Function	Overrange <sup>1</sup>	Underrange <sup>2</sup>
DC Functions: Voltage, Current, Resistance, and Diode	<ul> <li>All ranges, except 300 V and 1 A (NI 4070/4072) or 1000 V and 3 A (NI 4071):</li> <li>Occurs above 105% of the range.</li> <li>Above 105%, NI-DMM returns NaN<sup>3</sup> (except for the 100 MΩ range on the NI 4070/4072) and the IVI overrange warning.</li> <li>For the 100 MΩ range on the NI 4070/4072, measurements between the 105 MΩ and 1.05 GΩ ranges have a typical accuracy of 5%, although NI- DMM returns the IVI overrange warning. For measurements above 1.05 GΩ, NI-DMM returns NaN<sup>3</sup> and the IVI overrange warning instead of the reading.</li> <li>300 V and 1 A ranges (NI 4070/4072) or 1000 V and 3 A ranges (NI 4071):</li> </ul>	Not applicable

	<ul> <li>Occurs above 105% of the range.</li> <li>Above 105%, NI-DMM returns readings (not NaN<sup>3</sup>) and the IVI overrange warning, even though the readings are not guaranteed within specifications.</li> </ul>	
AC Functions: Voltage and Current	<ul> <li>All ranges, except 300 V and 1 A (NI 4070/4072) or 700 V and 3 A (NI 4071):</li> <li>Occurs above 105% of the range.</li> <li>Above 105%, NI-DMM returns readings (not NaN<sup>3</sup>) and the IVI overrange warning, even though the readings are not guaranteed within specifications.</li> <li>At significantly higher than 105%, NI-DMM returns a NaN<sup>3</sup> and the IVI overrange warning.</li> </ul>	Not applicable
	<ul> <li>300 V and 1 A ranges (NI 4070/4072) or 700 V and 3 A ranges (NI 4071):</li> <li>Occurs above 105% of the range.</li> <li>Above 105%, NI-DMM returns readings (not</li> </ul>	

	NaN <sup>3</sup> ) and the IVI overrange warning, even though the readings are not guaranteed within specifications.	
Frequency/Period	Not applicable	<ul> <li>Occurs when the signal amplitude is below 5% of the voltage range<sup>4</sup>.</li> <li>Below 5%, NI-DMM returns –Inf and the NI- DMM underrange warning.</li> </ul>
Capacitance (NI 4072 only)	<ul> <li>Occurs above 110% of the range.</li> <li>Above 110%, NI-DMM returns readings (non NaN<sup>3</sup>) and the IVI overrange warning, even though the readings are not guaranteed within specifications.</li> </ul>	<ul> <li>Occurs below 5% of the range, except in the 300 pF range. The 300 pF range does <i>not</i> have underrange.</li> <li>Below 5%, NI-DMM returns –Inf and the NI-DMM underrange warning.</li> </ul>
Inductance	Occurs above 110% of	Can occur

IVI overrange warning.	ranges when the signal is too weak for the measurement to occur. In such cases, NI- DMM returns 0 H and the NI-DMM underrange warning.
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<sup>1</sup>Refer to the *National Instruments IVI Help* at <u>ni.com/manuals</u> for the IVI overrange warning code.

<sup>2</sup>Refer to the <u>Error and Warning Codes</u> section for the NI-DMM underrange warning code.

<sup>3</sup> NaN is a digital display value for a floating-point representation of "Not a Number," as defined by the IEEE standard for binary floating point arithmetic. NaN is typically the result of an undefined operation, such as log(-1).

<sup>4</sup>Frequency voltage range is a property with the same allowed values as for the AC voltage ranges. Refer to <u>Frequency/Period</u> and <u>Frequency</u> <u>Voltage Range</u> for more information.

#### NI 4065

Function	Overrange <sup>1</sup>	
DC Functions:	All ranges, except 300 V and 3 A:	
	<ul> <li>Occurs above 105% of the range.</li> </ul>	
Voltage, Current, Resistance,	<ul> <li>Above 105%, NI-DMM returns NaN<sup>3</sup> (except for the 100 MΩ range on the NI 4065) and the IVI overrange warning.</li> </ul>	

and Diode	<ul> <li>For the 100 MΩ range on the NI 4065, measurements between the 105 MΩ and 1.05 GΩ ranges have a typical accuracy of 5%, although NI-DMM returns the IVI overrange warning. For measurements above 1.05 GΩ, NI- DMM returns NaN<sup>3</sup> and the IVI overrange warning instead of the reading.</li> </ul>
	<ul> <li>300 V and 3 A ranges:</li> <li>Occurs above 100% of the range.</li> <li>Above 100%, NI-DMM returns readings (not NaN<sup>3</sup>) and the IVI overrange warning, even though the readings are not guaranteed within specifications.</li> </ul>
AC Functions: Voltage and Current	<ul> <li>All ranges, except 300 V and 3 A:</li> <li>Occurs above 105% of the range.</li> <li>Above 105%, NI-DMM returns NaN<sup>3</sup> and the IVI overrange warning.</li> </ul>
	<ul> <li>300 V and 3 A ranges:</li> <li>Occurs above 100% of the range.</li> <li>Above 100%, NI-DMM returns readings (not NaN<sup>3</sup>) and the IVI overrange warning, even though the readings are not guaranteed within specifications.</li> </ul>
overrange war	<i>Jational Instruments IVI Help</i> at <u>ni.com/manuals</u> for the IVI ning code. tal display value for a floating-point representation of "Not

<sup>3</sup> NaN is a digital display value for a floating-point representation of "Not a Number," as defined by the IEEE standard for binary floating point arithmetic. NaN is typically the result of an undefined operation, such as log(-1).

#### NI 4060

Function	Range	Overrange (V) <sup>1</sup>	Overrange (%) <sup>1</sup>
DC and AC Voltage	DC and AC Voltage 250 V		120%
	25 V	27 V	108%
	2 V	2.2 V	110%
	200 mV	220 mV	110%
	20 mV	22 mV	110%
DC and AC Current	20 mA	22 mA	110%
	200 mA	220 mA	110%
Resistance (2- and 4- Wire)	Extended >2 MΩ	None	100%
	2 ΜΩ	None	100%
	200 kΩ	None	100%
	20 kΩ	None	100%
	2 kΩ	None	100%
	200 Ω	None	100%
Diode	2 V	2.2 V	110%

<sup>1</sup>NI-DMM returns NaN and the IVI overrange warning when measurement values exceed the overrange limits on the NI 4060. Refer to the *National Instruments IVI Help* at <u>ni.com/manuals</u> for the IVI overrange warning code.

NaN is a digital display value for a floating-point representation of "Not a Number," as defined by the IEEE standard for binary floating point arithmetic. NaN is typically the result of an undefined operation, such as log(-1).

#### NI 4050

Function	Range	Overrange (V) <sup>1</sup>	Overrange (%) <sup>1</sup>
DC and AC Voltage	250 V	None	100%
	25 V	27 V	108%
	2 V	2.2 V	110%

	200 mV	220 mV	110%
	20 mV	22 mV	110%
DC and AC Current	20 mA	22 mA	110%
	200 mA	220 mA	110%
Resistance (2- and 4- Wire)	Extended >2 MΩ	None	100%
	2 ΜΩ	None	100%
	200 kΩ	None	100%
	20 kΩ	None	100%
	2 kΩ	None	100%
	200 Ω	None	100%
Diode	2 V	2.2 V	110%

<sup>1</sup>NI-DMM returns NaN and the IVI overrange warning when measurement values exceed the overrange limits on the NI 4050. Refer to the *National Instruments IVI Help* at <u>ni.com/manuals</u> for the IVI overrange warning code.

NaN is a digital display value for a floating-point representation of "Not a Number," as defined by the IEEE standard for binary floating point arithmetic. NaN is typically the result of an undefined operation, such as log(-1).

# **DMM Measurement Defaults**

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The following table lists the default measurement settings for the NI 4070/4071/4072.

Function	<u>Aperture</u>	<u>Auto</u> Zero	ADC Calibration	<u>DC</u> <u>Noise</u> <u>Rejection</u>
DC 7 <sup>1</sup> / <sub>2</sub> digits <sup>1</sup>	100 ms	ON	ON	High- Order
DC 6 <sup>1</sup> / <sub>2</sub> digits	100 ms	ON	ON	High- Order
DC 5½ digits	<ul> <li>500 μs (NI 4070/4072)</li> <li>500 μs<sup>2</sup> (NI 4071)</li> </ul>	ONCE	OFF	Second- Order
DC 4½ digits	<ul> <li>20 μs (NI 4070/4072)</li> <li>50 μs (NI 4071)</li> </ul>	ONCE	OFF	Second- Order
DC Auto Range	500 μs	ONCE	OFF	Second- Order
AC	Max (DC or 4/(minFreq))	OFF	OFF	N/A
AC Auto Range	Max (500 μs or 4/(minFreq))	OFF	OFF	N/A
Frequency	2/(minFreq)	N/A	N/A	N/A
Period	2 x (the maximum period)	N/A	N/A	N/A
Capacitance and Inductance	<ul> <li>Inductance (only) at 10 kHz = 13.65 ms</li> <li>Inductance and capacitance at 1 kHz = 125.2 ms</li> <li>Inductance and capacitance at 91 Hz = 1.081 s</li> </ul>	N/A	N/A	N/A

<sup>1</sup>The default Number of Averages for the NI 4071 is 4. <sup>2</sup>For the NI 4071, on the 5.5 DCV 100V range, use 1.6 ms.

By default, the Aperture time, Auto Zero, ADC Calibration, DC Noise Rejection settings for a measurement are chosen by the driver based on the configured measurement and resolution. These values are chosen to ensure accuracy for 6½–digit or 7½–digit measurements while not sacrificing performance at lower resolutions. For more information on a particular attribute, including how to configure a non-default setting, refer to <u>Features</u>. For AC, excluding Auto Range, the aperture is expressed as Max (DC or 4/minFreq). minFreq, or minimum frequency, is a user– programmable parameter with a default value of 20 Hz. Therefore, the aperture default is 200 ms.

The same applies for other user selectable values of minFreq. For example, on the NI 4070/4071/4072, if a minFreq of 1 kHz is selected then 4/minFreq = 4/1 kHz = 4 ms. In this case 4 ms would be used as the AC aperture for resolutions <6 digits. For resolutions >6 digits, 100 ms would be used.

To adjust the default aperture time, refer to <u>Configuring Measurement</u> <u>Timing</u>.

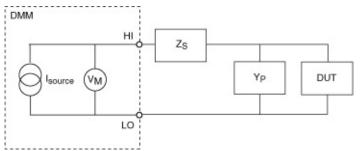
# **Default Settling Times**

Function	Settling Time
DC V (100 mV–10 V)	1 ms
DC V (100 V, 300 V) (NI 4070/4072 only)	2 ms
DC V (100 V, 1000 V) (NI 4071 only)	5 ms
DCV Auto Range	2 ms
Resistance ≤1 kΩ	1 ms
Resistance 10 kΩ	5 ms
Resistance 100 k $\Omega$	25 ms
Resistance 1 M $\Omega$	100 ms
Resistance $\geq 10 \text{ M}\Omega$	250 ms
Resistance Auto Range	50 ms
AC V DC coupled	3 µs
AC V AC coupled	1 s
Frequency/Period	500 ms
DC I	100 µs
AC I	3 µs
Diode	10 ms
Inductance (NI 4072 only)	3 µs
Capacitance (NI 4072 only)	3 µs

To adjust the default settling times, refer to <u>Configuring Measurement</u> <u>Timing</u>.

# Capacitance/Inductance

The NI 4072 uses a 2-wire, multi-tone, constant current technique to measure impedance. When a multi-tone constant current source ( $I_{src}$ ) is applied to the device under test (DUT), the NI 4072 measures the fundamental and third harmonic of the voltage waveform.



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**Note** Bold values denote vector quantities or complex numbers.

When the current and voltage are known, the NI 4072 calculates the capacitance or inductance using FFT peak analysis.

If the residual series impedance ( $Z_s$ ) and the stray parallel admittance ( $Y_p$ ) introduce a significant error in the measurement, the NI 4072 can measure the magnitude of the error and reduce it using compensation techniques. For more information, refer to the <u>OPEN/SHORT</u> <u>Compensation</u> section.

Refer to the  $\underline{NI \ 4072}$  section for the measurement ranges on the NI 4072 for the capacitance and inductance modes.

### **Theoretical Background**

The following topics include background information about capacitance and inductance measurements:

- Impedance
- Admittance
- <u>Capacitors</u>
- Inductors

#### Impedance

Capacitive and inductive loads oppose the flow of alternating currents. This opposition is expressed as impedance at a given frequency. The effect of a real-world impedance load is observed as an attenuation of the signal and a phase shift. Because of the nature of the impedance, it is denoted as a vector whose angle is the same as the phase angle between voltage and current, and the magnitude of the impedance is the same as the quotient between the voltage and current magnitudes, as follows:

Note Bold values denote vector quantities or complex numbers.

*Z* = *V*/*I* 

Numerically, the impedance vector is represented as a complex number either in polar form (magnitude and phase) or rectangular form (real and imaginary). The following equation expresses impedance in rectangular form:

 $\boldsymbol{Z} = \boldsymbol{R} + \boldsymbol{j}\boldsymbol{X}$ 

where *R* and *X* are resistance and reactance, respectively. When X = 0, the load is purely resistive; when R = 0, the load is purely reactive. For capacitors, the reactance can be expressed as follows:

 $X_c = -1/(2\pi f C_s)$ 

For inductors, the reactance can be expressed as follows:

 $X_L = 2 \pi f L_s$ 

#### Admittance

To simplify mathematical manipulation, calculation, and analysis, it is sometimes convenient to express the impedance as its reciprocal quantity, or admittance. Admittance is defined as

Y = 1/Z = I/V

and can be written as

$$\mathbf{Y} = \mathbf{G} + \mathbf{j}\mathbf{B}$$

where G and B are the rectangular (real and imaginary) components, known as conductance and susceptance respectively. The conductance G is the reciprocal of the parallel resistance, as follows:

 $G = 1/R_P$ 

The susceptance for capacitors is expressed as follows:

 $B_C = 2_{\pi} f C_P = 1/X_C$ 

The susceptance for inductors is expressed as follows:

 $B_L = 1/2_{\pi} f L_P = 1/X_L$ 

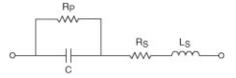
### Capacitors

A capacitor is an electronic component that is capable of storing energy as charge. Each capacitor consists of two plates of conductive material that are separated by a dielectric, which could be air, paper, plastic, oxide or any other type of insulator. The dielectric constant, or *K*, of an insulator represents its ability to store charge. The table below shows the *K* values for different dielectric materials:

Dielectric	Dielectric Constant (K)
Vacuum	1
Air	1.0001
Teflon	2.0
Polypropylene	2.1
Polystyrene	2.5
Polycarbonate	2.9
Polyester	3.2
FR-4	3.8–5.0
Glass	4.0–8.5
Mica	6.5–8.7
Ceramics	6 to several thousand
Aluminum oxide	7
Tantalum oxide	11

The electrical properties of insulators show variability with factors such as temperature, frequency, voltage, and humidity. This variability and the mechanical construction of the capacitor create a less than ideal device.

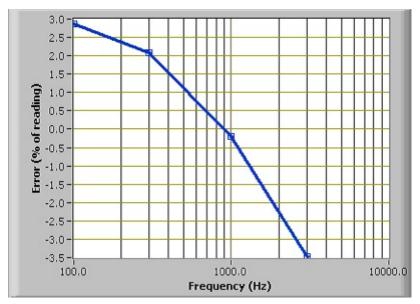
A better representation of real-world capacitors is shown in the equivalent model below, which aids in understanding the different parasitic elements that are present in a real-world component. These parasitic elements impact the capacitor impedance at different test frequencies.



The parallel resistance, *Rp*, is usually a large value, and its effect is

significant only when measuring capacitors with small values. The equivalent series resistance, *Rs*, although a small value, is important in capacitors with large values, where the impedance is small compared to *Rs* and where high power is dissipated. The series inductance, *Ls*, represents the total inductance and capacitance roll-off at higher frequencies.

At low frequencies, capacitance varies with frequency and the test signal level, due to changes in the dielectric properties. The following graph shows a 2.2  $\mu$ F 100 V aluminum electrolytic capacitor measured at different frequencies. The error is referenced to the measurement using a 1 V<sub>rms</sub> AC test signal at 1 kHz.



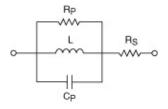
These factors cause capacitors to have different values under varying conditions of temperature, frequency, and signal level.

#### Inductors

An inductor is an electronic component that is capable of storing energy as current. Each inductor consists of a conductive coil that can be wrapped without a core or around a magnetic material. The permeability of the core material is a measure of the intensity of the magnetic field that can be induced in it.

The electrical properties of the cores show variability with factors such as temperature, frequency, current, and so on. This variability and the mechanical construction of the inductor create a less than ideal device.

A better representation of real-world inductors is shown in the equivalent model below, which aids in understanding the different parasitic elements that are present in a real-world component. These parasitic elements impact the inductor impedance at different test frequencies.



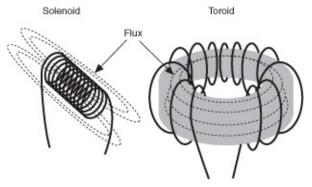
The series resistance, Rs, represents the resistive losses in the conductor. The parallel capacitance, Cp, is the equivalent capacitive effect between the turns of the coil, and the parallel resistance, Rp, is the sum of all losses attributable to the core material.

Air cores require many more turns in the coil to achieve high-inductance values. Thus, air cores are often impractical for applications, due to their large size and weight. Also, air cores usually have a large winding capacitance and a series resistance with a high-inductance value.

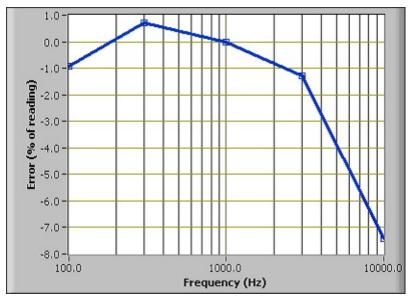
Not all parasitics affect the value of the inductor, but some parasitics are more prominent than others, depending upon the construction of the coil, the geometry of the inductor, the gauge of the wire, and the characteristics of the core. The value of the inductor and the magnitude of each type of parasitic in relation to the other types of parasitics determine the frequency response.

The geometry of some components can increase the sensitivity of the components to external factors, and this increased sensitivity can also affect the value of the inductor. Open flux inductors are more sensitive to metallic materials that are in close proximity, because such materials

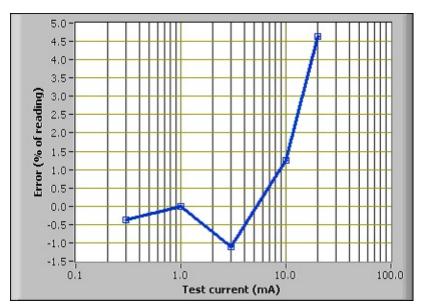
modify the magnetic field. Toroidal inductors keep the flux inside the core and are less sensitive to external conductors in close proximity. Refer to the following figure to view the flux associated with these types of inductors:



In the following graph, a 5 mH air-core inductor is measured over different frequencies. The error is referenced to the measurement with a test signal of 1  $V_{rms}$  at 1 kHz. This type of inductor has a high degree of winding capacitance due to the size and number of turns required for its construction. Therefore, this type of inductor measures as if there were a strong variation of inductance with frequency.



Some ferrite cores are expected to vary greatly with the test signal level. In the following graph, a 100 uH ferrite-core inductor is tested at different test signal levels. The error is referenced to the measurement with a test signal of  $1 \text{ mA}_{rms}$  at 1 kHz.



All of these factors can combine and cause inductors to have different values under varying conditions of temperature, frequency, and signal level.

### Model

In real-world applications, devices are neither purely reactive nor purely resistive. However, they can be easily modeled either as a series or parallel combination of a resistive and a reactive load using the formulas above.



In general, it is mathematically easier to manipulate parallel loads as admittances and series loads as impedances.



You model the result as a series or parallel model based upon which resistance,  $R_S$  or  $R_P$ , is more significant. The parallel resistance ( $R_P$ ) is typically larger than the series resistance ( $R_S$ ). To measure small reactive values, such as high-valued capacitors and low-valued inductors, it is preferable to use the series model, because the series resistance is more significant than the parallel resistance. When measuring large reactive values, such as high-valued inductors or low-valued capacitors, it is preferable to use the parallel model.

Type of Measurement	Range	Impedance	Model	
С	>100 uF	<10 Ω	Series	
С	10 nF to 100 uF	10 Ω to 10 kΩ	Series or parallel	
С	<10 nF	>10 kΩ	Parallel	
L	<1 mH	<10 Ω	Series	

L	1 mH to 1 H	10 Ω to 1 kΩ	Series or parallel		
L	>1 H	≥1 kΩ	Parallel		
<b>Note:</b> Impedance values are calculated at the test frequency used on the NI 4072 at each specified range.					

### **Test Signal**

The NI 4072 uses an AC current source as excitation for capacitance and inductance measurements. The current waveform is a very stable, harmonically limited square wave. The measurement method extracts multiple-tone information contained in the test signal to find the capacitance or inductance of the device under test. The frequency and level of the test signal and the tones extracted from it are shown in the following tables:

Capacitance						
Fundamental		Third Harmonic		Effective Test Signal		
	Frequency	Current	Frequency	Current	Frequency	Current
300 pF	1 kHz	0.5 μΑ	3 kHz	0.16 μΑ	3 kHz	0.16 μΑ
1 nF				·		
10 nF	1 kHz	1 µA	3 kHz	0.33 µA	3 kHz	0.33 µA
100 nF	1 kHz	10 µA	3 kHz	3.3 µA	3 kHz	3.3 μΑ
1 uF	1 kHz	100 µA	3 kHz	33 μΑ	1 kHz	100 µA
10 uF	1 kHz	1 mA	3 kHz	330 µA	1 kHz	1 mA
100 uF				·		
1,000 uF	01 11-	1 m 4	272 1 17	220 ^	01 11-	1 m 4
10,000 uF	91 Hz	1 mA	273 Hz	330 µA	AT HT	1 mA

Inductance						
Range	Fundamental		Third Harmonic		Effective Test Signal	
	Frequency	Current	Frequency	Current	Frequency	Current
10 uH						
100 uH	10 kHz	1 mA	30 kHz	330 µA	30 kHz	330 µA

1 mH	1 kHz	1 mA	3 kHz	330 µA	3 kHz	330 µA
10 mH	1 kHz	10 µA	3 kHz	3.3 µA	3 kHz	3.3 µA
100 mH	91 Hz	100 µA	273 Hz	33 µA	273 Hz	33 µA
1 H	91 Hz	10 µA	273 Hz	3.3 µA	273 Hz	3.3 µA
5 H	91 Hz	1 μΑ	273 Hz	0.33 μΑ	273 Hz	0.33 μΑ

The digitizer measures the DUT impedance at two frequencies (tones). From these two measurements, the losses are calculated (front-end, cabling, and DUT). Using the calculated losses, the software computes the capacitance or inductance at one of the two frequencies (effective frequency).

The effective test signal is included as a reference. It is the signal that would yield a comparable capacitance or inductance value if measured with the single tone measurement technique.

### **Measurement Considerations**

When taking capacitance and inductance measurements with the NI 4072, consider the following:

- Frequency effects of real-world components
- <u>Temperature effects</u>
- Cabling
- Noise pickup

### **Frequency Effects of Real-World Components**

Due to the parasitics and materials used in the construction of real-world components, the measured capacitance or inductance value can differ from one instrument to another. When measuring capacitors with better dielectric properties, you observe much smaller reading differences between various instruments. This observation also applies to inductors with better magnetics.

The following table shows some examples of dielectrics with good and poor frequency characteristics:

Dielectrics with Good Frequency	Dielectrics with Poor Frequency
Characteristics	Characteristics
<ul> <li>Teflon</li> <li>Mica</li> <li>Polypropylene</li> <li>Polycarbonate</li> <li>Ceramic COG</li> </ul>	<ul> <li>Tantalum oxide</li> <li>Aluminum oxide</li> <li>Ceramic Y5U</li> </ul>

Due to the amount of magnetization current required, you can see an increase in sensitivity to frequency changes and other dependency factors in inductors with cores of larger dimensions, such as those used in transformers and power inductors.

#### **Temperature Effects**

Temperature can have a large impact on the DUT impedance. Usually, capacitors have large temperature coefficients (5% to 80% variation over the entire temperature range, depending upon the capacitor used) except for ceramic COG capacitors, which can exhibit only a 0.003%/°C variation. Inductors, especially those with non-air cores, may vary largely with temperature. Ambient and DUT temperature drifts (due to handling, for instance) may introduce error into the measurement. Control ambient temperature changes to reduce errors.

### Cabling

To reduce variations on the system parasitics, NI recommends using coaxial cable or shielded twisted pairs, with the shield used as the current return path and connected to the LO input of the DMM. This configuration makes the <u>OPEN/SHORT compensation</u> more practical and helps to reduce the noise pickup.

For manual probing of surface mount parts, you can use a pair of tweezers. The NI 4072 can compensate for the impedance introduced by the test fixtures. Refer to the <u>OPEN/SHORT Compensation</u> section for more information. Reduce the mechanical variations (for example, movement or flexing of cables, or changing fixturing) between two consecutive measurements to maintain repeatability.

Use a high-quality cable, such as Belden 83317E available at <u>www.belden.com</u>. NI recommends cables with Teflon, polypropylene, or polyethylene insulation. For more information about cabling requirements, refer to <u>Interconnects and Cables</u>. Very good performance has been achieved using up to 25 feet of this cable in both capacitance and inductance measurements by performing OPEN/SHORT compensation prior to the measurement.

#### **Noise Pickup**

To minimize noise pickup, keep cables, the setup, and the DUT away from any electromagnetic noise sources such as motors, transformers, and cathode ray tubes (CRTs). Avoid frequency sources around 91 Hz, 1 kHz, 10 kHz, and the respective harmonics, because these frequencies are the frequencies of the excitation currents used by the NI 4072. Use shielded cable (BNC connectors and coaxial cable are recommended) for cabling and for connecting the external conductor to the LO input of the DMM.



**Note** For more information about using the NI 4072 as part of an automated test equipment (ATE) system, refer to the <u>Switching</u> <u>Capacitance and Inductance</u> section.

## DC Bias

To test some polarized components, such as electrolytic and tantalum capacitors, it may be preferable to use only positive voltages. During normal operation, the AC current source swings negative 50% of the time, which results in an inverse polarization of the capacitor under test. To prevent this inverse polarization, you can apply a DC bias to prevent the voltage across the part from becoming negative.



**Note** When DC Bias is turned ON, the high potential appears on the HI terminal. Ensure that the component is polarized correctly by connecting the negative terminal of the component to the LO terminal.

The DC bias voltage is a fixed value and can only be turned on and off. The nominal voltage value is 0.45 V and can be used for any capacitance range. The default setting is OFF.

## **OPEN/SHORT** Compensation

In most practical applications, the DMM is connected to the DUT with switches and/or fixtures. These switches and fixtures can introduce undesired errors into the measurement. **Compensation** minimizes the errors between the NI 4072 and the DUT.

#### **Offset Compensation**

Compensation consists of measuring the error and applying the measured error to the actual measurement to correct and minimize the errors introduced by the test system. The compensation functions must be set before taking any measurement at a specified function and range.

Any change in range or function defaults the compensation type to none. Therefore, you must calculate these values again. To provide maximum flexibility in the test system, the compensation values are returned by the API. You can manipulate, store, and load these values for high channelcount systems.

To perform **OPEN compensation** for capacitance and inductance measurements, complete the following steps:

- 1. Disconnect the DUT from the DMM at the DUT.
- 2. Configure the DMM for capacitance or inductance at the desired range.
- 3. Call <u>niDMM Configure Cable Comp Type</u> or <u>niDMM\_ConfigureCableCompType</u>, and set the Cable Comp Type to CABLE COMP OPEN.
- 4. Set up an open condition, where nothing is connected to the test fixture. If the switching system in use has similar capacitance on different channels, you can dedicate one channel for open measurements. Cables and switches with low capacitance and low-path resistance are recommended.
- 5. In LabVIEW, call <u>niDMM Perform Open Cable Comp</u> or <u>niDMM\_PerformOpenCableComp</u> while the input to the DMM is open. This VI or function returns two values: conductance and susceptance.
- 6. Pass the two values from the previous step into <u>niDMM Configure</u> <u>Open Cable Comp Values</u> or <u>niDMM\_ConfigureOpenCableCompValues</u>. Passing these values

subtracts the open measurement from all subsequent measurements.

7. Perform the desired measurement.

To perform **SHORT compensation** for capacitance and inductance measurements, complete the following steps:

- 1. Disconnect the DUT from the DMM at the DUT.
- 2. Configure the DMM for capacitance or inductance at the desired range.
- 3. Call <u>niDMM Configure Cable Comp Type</u> or <u>niDMM\_ConfigureCableCompType</u>, and set the Cable Comp Type to CABLE COMP SHORT.
- 4. Set up a short condition at the end of the test fixture, using a lowimpedance connection between the HI and LO terminals. If the switching system in use has similar inductance on different channels, you can dedicate one channel for short measurements. Cables and switches with low capacitance and low path resistance are recommended.
- 5. In LabVIEW, call <u>niDMM Perform Short Cable Comp</u> or <u>niDMM\_PerformShortCableComp</u> while the input to the DMM is shorted. This VI or function returns two values: resistance and reactance.
- Pass the two values from the previous step into <u>niDMM Configure</u> <u>Short Cable Comp Values</u> or <u>niDMM\_ConfigureShortCableCompValues</u>. Passing these values subtracts the short measurement from all subsequent measurements.
- 7. Perform the desired measurement.

### **OPEN/SHORT** Compensation

To perform **OPEN and SHORT compensation** for capacitance and inductance measurements, complete the following steps:

- 1. Disconnect the DUT from the DMM at the DUT.
- 2. Configure the DMM for capacitance or inductance at the desired range.
- 3. Call <u>niDMM Configure Cable Comp Type</u> or <u>niDMM\_ConfigureCableCompType</u>, and set the Cable Comp Type

to CABLE COMP OPEN AND SHORT.

- 4. Set up an open condition, where nothing is connected to the test fixture. If the switching system in use has similar inductance on different channels, you can dedicate one channel for open measurements. Cables and switches with low capacitance and low path resistance are recommended.
- 5. Call <u>niDMM Perform Open Cable Comp</u> or <u>niDMM\_PerformOpenCableComp</u> while the input to the DMM is shorted. This VI or function returns two values: conductance and susceptance.
- 6. Pass the two values from the previous step into <u>niDMM Configure</u> <u>Open Cable Comp Values</u> or <u>niDMM\_ConfigureOpenCableCompValues</u>.
- 7. Set up a short condition at the end of the test fixture, using a lowimpedance connection between the HI and LO terminals. If the switching system in use has similar inductance on different channels, you can dedicate one channel for short measurements. Cables and switches with low capacitance and low path resistance are recommended.
- 8. Call <u>niDMM Perform Short Cable Comp</u> or <u>niDMM\_PerformShortCableComp</u> while the input to the DMM is shorted. This VI or function returns two values: resistance and reactance.
- 9. Pass the two values from the previous step into <u>niDMM Configure</u> <u>Short Cable Comp Values</u> or <u>niDMM\_ConfigureShortCableCompValues</u>.
- 10. NI-DMM takes the four values measured on open and short conditions to compensate all subsequent measurements.
- 11. Perform the desired measurement.
- Note Due to ambient temperature variations and other environment changes, such as humidity, it may be necessary to perform OPEN and SHORT compensation at least once a day. When using a switching system, verify that the OPEN and SHORT measurements on the reference channel closely match the measurements on the rest of the channels being compensated. If this compensation method does not meet your error budget requirements, OPEN and/or SHORT compensation must be

performed on the same channel used to take the DUT measurements.

# **Offset Nulling**

Offset nulling consists of measuring the corresponding zero reading in a measurement path and subtracting this value from subsequent samples.

The way you connect the leads to obtain the zero reading depends upon the type of measurement you are taking.

To perform offset nulling, complete the following steps:

- 1. Disconnect the DUT from the leads that are connected to the DMM.
- 2. If you are measuring DC voltage, inductance, or resistance, short the input leads to obtain the corresponding zero reading. If you are measuring DC current or capacitance, leave the leads unconnected (open circuit) to obtain the corresponding zero reading. In a switching system, you can make the open-circuit or short-circuit measurement with channels dedicated as short or as an open. NI recommends using cables and switches with low thermal voltages and low-path resistance to minimize the offset introduced by the measurement path. Refer to <u>Thermal Voltages</u> for more information.
- 3. Record the value of the measurement.
- 4. Connect the leads to the DUT, and subtract the value measured in step 3 from all subsequent measurements.

The subtraction operation can be performed programmatically with the ADE, and the DMM SFP has an offset nulling feature.

For capacitance and inductance measurements, NI recommends using <u>OPEN/SHORT compensation</u> rather than offset nulling to remove offset errors. <u>OPEN/SHORT compensation</u> performs a fixture/cable characterization at the test frequency to compensate for offset and gain errors, while offset nulling only performs an arithmetic subtraction of the offset present in the fixture/cable.

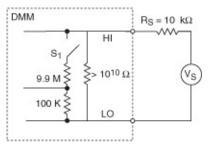
For resistance measurements in the ranges  $\leq 10 \text{ k}\Omega$ , you can enable <u>offset compensated ohms</u>, which removes offsets in the measurement path much better than offset nulling alone.

## **DC Voltage**

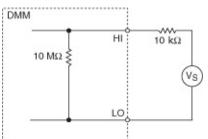
The NI 4065 and NI 4070/4071/4072 can measure signals in the submicrovolt range. To take accurate low-voltage measurements with confidence, consider the following factors: <u>thermal voltages</u>, selectable input resistance, and input bias current.

## **Selectable Input Resistance**

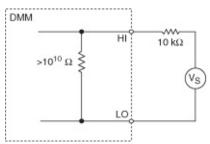
You can select the NI 4065 and NI 4070/4071/4072 DCV input resistance to optimize measurement performance in situations where large source resistance is present. In the following figure,  $S_1$  is used to select a 10 M $\Omega$  input resistance on the 0.1 V, 1 V, and 10 V DC ranges.



The following figure shows an equivalent circuit after the 10  $\mbox{M}\Omega$  input resistance has been selected:



The following figure shows an equivalent circuit after the 10 G $\Omega$  input resistance has been selected:



The following table lists the available NI 4070/4071/4072 input resistance selections. NI calibrates the NI 4070/4071/4072 for full accuracy with all input resistances shown.



**Note** The default input resistance for each range is italicized.

DCV		ACV	Waveform Acquisition		
Range	Input Resistance	Range	Input Resistance	Range	Input Resistance

	L		L		I
100 mV	<i>10 M</i> Ω or 10 GΩ	50 mV	1 MΩ (NI 4070, NI 4072); 10 MΩ (NI 4071)	100 mV	10 GΩ or <i>1 MΩ</i> (NI 4070, NI 4072); 10 GΩ or <i>10 M</i> Ω (NI 4071)
1 V	<i>10 M</i> Ω or 10 GΩ	500 mV	1 MΩ (NI 4070, NI 4072); 10 MΩ (NI 4071)	1 V	10 GΩ or <i>1 MΩ</i> (NI 4070, NI 4072); <i>10 M</i> Ω (NI 4071)
10 V	<i>10 M</i> Ω or 10 GΩ	5 V	1 MΩ (NI 4070, NI 4072); 10 MΩ (NI 4071)	10 V	10 GΩ or <i>1 MΩ</i> (NI 4070, NI 4072); <i>10 M</i> Ω (NI 4071)
100 V	10 ΜΩ	50 V	1 MΩ (NI 4070, NI 4072); 10 MΩ (NI 4071)	100 V	1 <i>M</i> Ω (NI 4070, NI 4072); <i>10 M</i> Ω (NI 4071)
300 V	<i>10 MΩ</i> (NI 4070, NI 4072)	300 V	1 MΩ (NI 4070, NI 4072)	300 V	<i>1 M</i> Ω (NI 4070, NI 4072)
1000 V	<i>10 ΜΩ</i> (NI 4071)	700 V	10 MΩ (NI 4071)	1000 V	<i>10 M</i> Ω (NI 4071)

The following table lists the available NI 4065 input resistance selections. NI calibrates the NI 4065 for full accuracy with all input resistances shown.

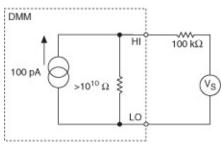
 $\infty$  Note The default input resistance for each range is italicized.

	DCV	ACV	
Range	Input Resistance	Range	Input Resistance
100 mV	<i>10 M</i> Ω or 10 GΩ	200 mV	10 MΩ

1 V	<i>10 MΩ</i> or 10 GΩ	2 V	10 MΩ
10 V	<i>10 M</i> Ω or 10 GΩ	20 V	10 MΩ
100 V	10 ΜΩ	300 V	10 MΩ
300 V	10 MΩ		

#### **Input Bias Current**

If the source resistance is greater than 10 k $\Omega$ , then you may need to include the effects of input bias current in addition to input resistance. For example, for 100 k $\Omega$  source resistance, a 100 pA bias current creates an offset error of 10  $\mu$ V, as shown in the following figure.



With an input resistance of >10 G $\Omega$  selected, most of the input bias current flows through the source resistance (100 k $\Omega$ ), causing an offset voltage.

DMM input bias current approximately doubles for every 10 °C of environmental temperature change. For example, an input bias current of 25 pA at 23 °C translates to about 50 pA at 33 °C, 100 pA at 43 °C, and so on. Likewise, as temperature is decreased, the current drops 50% for every 10 °C. Thus, at 13 °C, the input bias current is approximately 12.5 pA.

## **DC Noise Rejection**

DC noise rejection is a <u>configurable</u> noise reduction feature available for NI 4065 and NI 4070/4071/4072 DC measurements. Each DC reading the NI 4070/4071/4072 returns is actually an average of multiple high-speed samples. By adjusting the relative weighting of those samples, you can adjust the sensitivity to different interfering frequencies. The NI 4070/4071/4072 offers three different modes: normal, second-order, and high-order.

Note The NI 4065 does *not* support high-order.

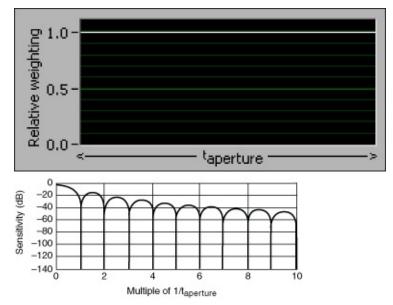
Refer to the following table for a list of the differences between the three modes:

DC Noise Rejection Setting	Lowest Frequency for Noise Rejection	High-Frequency Noise Rejection
Normal	1/t <sub>aperture</sub>	Good
Second-Order	2/t <sub>aperture</sub>	Better
High-Order	4/t <sub>aperture</sub>	Best

Refer to the <u>Aperture Time</u> table for the default aperture times and DC noise rejection settings used by the DMM.

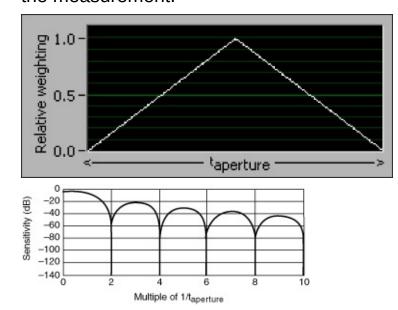
#### Normal

When you select normal DC noise rejection, the NI 4065 and NI 4070/4071/4072 weight all samples equally. This feature emulates the behavior of most traditional DMMs, providing good rejection of frequencies at multiples of *f0*, where  $f0 = 1/t_{aperture}$ . The following figure shows normal weighting, where all samples are weighted equally, and the resulting noise rejection as a function of frequency. Notice that you can obtain good rejection only very near multiples of *f0*. To get the fastest possible readings that give you some powerline noise rejection, set the aperture to the powerline period, such as 16.667 msec for a 60 Hz powerline frequency, and set the DC noise rejection to normal.



#### Second-Order

Second-order DC noise rejection applies a triangular weighting to the measurement samples, as shown in the following figure. In second-order DC noise rejection, the samples taken in the middle of the aperture time are weighted more than samples taken at the beginning and the end of the measurement.

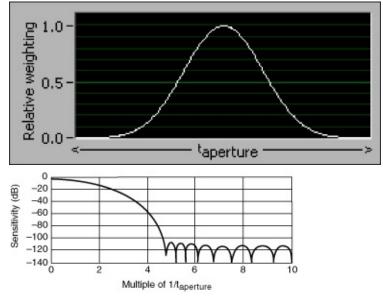


Notice that you can obtain very good rejection near even multiples of *fO* and that rejection increases more rapidly with frequency than with normal sample weighting. Also notice that the response notches are wider than they are with normal weighting, resulting in less sensitivity to slight variations in noise frequency. Use second-order DC noise rejection if you

need better powerline noise rejection than you can get with normal DC noise rejection, but cannot afford to read slowly enough to take advantage of high-order noise rejection. For example, you could <u>set the aperture</u> to 33.333 msec for a 60 Hz powerline frequency.

#### **High-Order**

The following figure shows high-order sample weighting and its resulting noise rejection as a function of frequency:



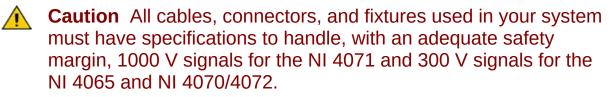


Note The NI 4065 does not support high-order.

Notice that noise rejection is good starting at around four times *f0* and is excellent above about 4.5 times *f0*. Sensitivity to noise at any frequency above 4.6 times *f0* almost does not exist. An NI 4070/4071/4072, using high-order DC noise rejection with a 100 msec aperture (10 readings/sec), can deliver full  $6\frac{1}{2}$  digit accuracy with over 1 V of interfering powerline noise on the 10 V range at any frequency above 46 Hz.

The small tradeoff to using the higher-order filters is that to obtain powerline rejection, you must increase the measurement aperture by 2x (for second-order) or 4x (for high-order) versus that required for the normal setting. The increase in aperture time is typically minimal given the reduction in the interfering signal.

## Handling High DC Voltages



The NI 4065 and NI 4070/4071/4072 inputs can measure sub- $\mu$ V level signals with low drift, handle 300 (NI 4065 and NI 4070/4072) or 1000 (NI 4071) VDC and peak VAC signals, and recover very quickly for sub- $\mu$ V level measurements in a system with switching. This ability is achieved through a flexible input protection design. Once the input exceeds about 15 V (NI 4070/4072) or 20 V (NI 4071) on the 10 V and lower ranges, the input protection triggers, and the input changes from a resistive characteristic to a constant current. This feature has the secondary benefit of reducing self-heating, so the DMM can recover rapidly to measure low-level signals with minimum recovery time.

However, you still need to consider that in a switching system where you are applying high voltages to a low range (for example, 300 V (NI 4065 and NI 4070/4072) or 1000 V (NI 4071) on the 10 V range), the switch receives a very short-duration current transient. The current transient does not cause any degradation effect on the NI 4065 and NI 4070/4071/4072. However, if the system switches an extreme overload to the DMM input mode with a moderate (tens of Hz) to high scanning rate over extended periods (weeks continuous or cumulative), the current transient can degrade the relay life in the switching system. For optimum switching system reliability when switching high voltages into any DMM, NI recommends selecting the range corresponding to the highest voltage expected.

Make sure that you do not exceed the V-Hz limit of the device, which is more likely to occur when measuring high-voltage/high-frequency signals; such action affects the internal transfer of data in the device and generates an error prompting you to reset the device and reconfigure the measurement.

Refer to <u>Switching Voltages</u> for recommendations on switching high voltages or signals with high common-mode voltage levels.

P

Tip If the NI 4070/4071/4072 experiences the conditions where

common-mode transients cause violation of the V-Hz limit of the instrument while the instrument is making measurements, the NI-DMM driver returns error NIDMM\_ERROR\_SERIAL\_PORT\_ERROR (defined as 0xBFFA401F, or -1074118625). If your system can potentially face this situation, your application should look for this error code after a call to:

- niDMM Read (niDMM\_Read)
- niDMM Read Multipoint (niDMM\_ReadMultipoint)
- niDMM Fetch (niDMM\_Fetch)
- niDMM Fetch Multipoint (niDMM\_FetchMultipoint)

Your application can handle this error by calling the following VIs or functions:

- 1. <u>niDMM Reset</u> (<u>niDMM\_reset</u>)
- 2. Any configuration VI or function to reconfigure the instrument to the required settings
- 3. <u>niDMM Initiate (niDMM\_Initiate)</u>, <u>niDMM Read</u> (<u>niDMM\_Read</u>), or <u>niDMM Read Multipoint</u> (<u>niDMM\_ReadMultipoint</u>) to restart the measurement

### **Optimizing Low-Voltage Measurements**

As discussed in <u>Thermal Voltages</u>, pairs of dissimilar metal junctions rather than a single junction—potentially can create problems. The NI 4070/4071/4072 uses proprietary gold-plated copper input leads (HI and LO). If you just connect these two jacks directly with some wire that is not copper, then you have two junctions of dissimilar metals. This basic concept can be extended to just about any other setup.

If the two jacks are at different temperatures, then a voltage is generated. The amplitude of the voltage depends on the other metal that is being used. If the other metal is copper, then the Seebeck coefficient for copper to copper is very low-well under 100 nV/°C, as long as the connections are clean and tight.

A temperature difference between the two jacks greater than 1–2 °C would be rare, but a temperature difference does exist. The interior of the PXI chassis is warmer than the outside air creating heat flow that ultimately results in a temperature difference.

For copper-to-copper connections, the generated voltage is relatively small. If you used brass instead of copper where a 1–2 °C temperature difference exists, there could be a 6  $\mu$ V difference in the measurement value detectable by the DMM.

One rule for low-voltage measurements is to always use metals with Seebeck coefficients close to that of copper. Copper, gold, and silver are all good candidates. Typical Seebeck coefficients for common conductors are listed in the <u>table</u> in <u>Thermal Voltage</u>.

If the connections do not change temperatures, then the thermal voltage is stable and can be corrected; it is temperature changes between these junctions that create problems (such as offset drift, instability, and very low frequency noise). The key to preventing changes in temperature is to prevent circulating air currents that can disturb the thermal equilibrium of the junctions. This leads to another rule for low-voltage measurementskeep junctions and connections at a stable temperature and away from circulating air currents caused by movement, fans, and so on. You can prevent these temperature differences by creating a "thermal baffle," such as wrapping the junctions with common foam padding (even Styrofoam sheet can work) and keeping them away from sources of heat such as equipment heat sinks and sunlight. Even common lead-tin solder connections can create thermal offsets of  $(1-3 \mu V/^{\circ}C)$ . While not insignificant, they can be managed using the techniques described above. For increased performance, cold weld connections by tightly twisting clean copper-to-copper connections together and then using either crimped or twist-on plastic connectors.

When copper oxidizes, the Seebeck coefficient can easily increase by several hundred  $\mu$ V/°C. This leads to another rule for low-voltage measurements-keep the connections clean. One option is to simply use a pencil eraser to clean the bare wire until the wire is shiny, then clean off any rubber fragments with a paper towel. Another way to clean connections is to use Scotchbrite pads to clean the wire. After cleaning the connections, do not handle the connections with your fingers. Skin oil contains a very effective corrosive that accelerates oxidation of many metals.

Refer to <u>Switching Voltages</u> for recommendations on reading low voltage signals through switches.

## **Selecting Aperture Time for DC Measurements**

The aperture time shapes the noise rejection of the measurement. Shorter aperture time yields a wider measurement bandwidth at the expense of resolution. Sensitivity to source noise increases with shorter apertures. Conversely, larger aperture times quiet noisy sources and yield higher resolution measurements. Refer to <u>Noise</u> for more information.

Selecting aperture times equal to multiples of power line frequency helps to reject these frequencies, when <u>DC Noise Rejection</u> is set to Normal. An aperture set to 1 powerline cycles (1 PLC equals 16.67 ms for 60 Hz powerline or 20 ms for 50 Hz) is the minimum that provides this line rejection.

Apertures of >100 ms can be used for measuring very high resistance values, when sensitivity to powerline frequency noise pickup is inevitable. Coupling the aperture time with <u>DC Noise Rejection</u> set to High Order provides extremely high noise rejection (>100 dB). Long apertures of >100 ms do not significantly improve resolution beyond 6½ digits but can provide better rejection to externally generated noise.

For voltage measurements with 7-digits resolution, average 4 or more 6½-digit Auto Zero measurements. You can average multiple measurements by setting the <u>Number of Averages</u> property to a value greater than one. Averaging with Auto Zero enabled circumvents the effects of low–frequency, self-generated noise and yields the highest resolution performance level. Having more averages also reduces external noise, but the tradeoff is speed.

Selecting apertures for AC is discussed in <u>AC Voltage Measurements</u>.

# **AC Voltage**

AC signals are typically characterized by their root-mean-square (rms) amplitude, which is a measure of their total energy. To compute the rms value of a waveform, you must take the square root of the mean value of the square of the signal level. Most DMMs, including the NI 4050, NI 4060, and NI 4065, do this nonlinear signal processing in the analog domain, but the NI 4070/4071/4072 uses an onboard digital signal processor (DSP) to compute the rms value from digitized samples of the AC waveform. By computing rms values (a traditionally analog problem) in the digital domain using the DSP chip, the NI 4070/4071/4072 speeds up AC measurements in two ways, as follows:

- Allows computation of fully-settled RMS values with only four cycles of the waveform
- Automatically rejects the DC component of the signal, making possible an AC Volts DC Coupled mode, which completely bypasses the slow-setting input coupling capacitor required on traditional DMMs

The result is quiet, accurate, and fast-settling AC readings.

The rms algorithm used by the NI 4070/4071/4072 requires at least 4 cycles of the waveform to obtain a quiet reading. For example, it requires a <u>measurement aperture</u> of 4 ms to accurately measure a 1 kHz sine wave. The measurement aperture also needs to be long enough to obtain the requested resolution. For example, although a 40  $\mu$ s aperture is long enough to measure the rms value of a 100 kHz sine wave, it is not long enough to obtain readings with 6½ digit accuracy. Thus, the period of the waveform being measured and the desired resolution both affect the necessary aperture. NI-DMM selects the shortest aperture to satisfy both requirements. Refer to the <u>Measurement Defaults</u> table for the aperture times used by the NI 4070/4071/4072, or to the <u>Measurement Defaults</u> table for the aperture times used by the NI 4070/4071/4072.

It is important to realize that it is the period of the measured waveform, and not the period of its lowest-frequency component, that determines the required minimum aperture as shown in Figures A, B, and C. Figure A shows a 1 kHz sine wave. That signal could be measured in 4 ms because that is 4 cycles of the waveform. Figure B shows a 1.1 kHz sine wave. It too could be measured in 4 ms because that is slightly more than 4 cycles of the waveform. Figure C shows a signal that is simply the sum of the signals in Figures A and B. Although the minimum frequency component of that signal is 1 kHz, 4 msec is clearly not long enough to measure the rms value of the whole signal. In this case, the signal has a period of 10 msec, so it requires a 40 msec aperture for an accurate measurement.

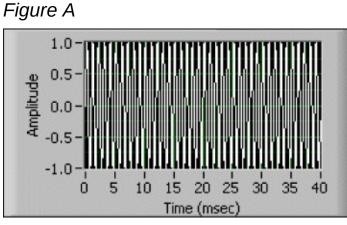


Figure B

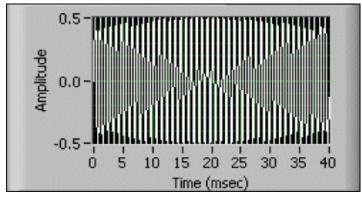
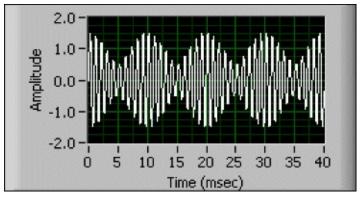


Figure C



## DC and AC Coupling

The NI 4070/4071/4072 offers two different modes for measuring AC voltage, and the NI 4065 offers one mode, as follows:

- AC Volts (NI 4070/4071/4072 and NI 4065)
- AC Volts DC Coupled (NI 4070/4071/4072 only)

#### AC Volts Mode

AC Volts mode on the NI 4065 and NI 4070/4071/4072 use a coupling capacitor to remove DC offsets before digitization. This functionality is standard in traditional DMMs. A coupling capacitor is available for situations where a large DC offset must be blocked before digitization. To measure AC voltage in the presence of large DC offsets, such as ripple on a DC power supply, use AC Volts mode, which uses a coupling capacitor to eliminate the offset.

#### AC Volts DC Coupled Mode

The rms algorithm employed by the NI 4070/4071/4072 digital signal processor (DSP) is completely insensitive to any DC component of the signal being measured. Therefore, for applications without large DC components, such as AC powerline and audio signals, the AC coupling capacitor used to block the DC signal component is not always necessary on the NI 4070/4071/4072. This capacitor can be bypassed by using AC Volts DC Coupled mode. This mode does not have the long time constant associated with the input coupling capacitor and thus offers a very short settling time.

#### **DC Coupling on AC Current Measurements**

AC current measurements are always DC coupled and therefore always offer quick settling time, but these measurements are subject to overload if the DC component of the signal exceeds the limits of the chosen range.

### **Frequency Response**

The NI 4070/4071/4072 uses a digital filter to ensure AC accuracy for all frequencies up to the specified limits. This filter is factory-calibrated for every AC mode and range. However, if care is not taken, it is still possible to get frequency-dependent measurement errors with the NI 4070/4071/4072. For example, a measurement of a source with a high impedance can yield lower-than-expected readings because of interaction with the input capacitance of the NI 4070/4071/4072. The NI 4070/4071/4072 accurately measures the level of the signal at its input, but the signal can be smaller than expected because of the loading effect of the capacitance. In such cases, it is advisable to either allow for the error or buffer the signal being measured.

## **AC RMS Noise**

Any noise added to the signal being measured can increase the apparent rms value of a signal. This applies both to external noise sources and to noise originating inside the NI 4070/4071/4072 itself. Due to the nature of the rms computation, added noise increases the reading in a nonlinear fashion. Specifically, if *S* is the rms value of the signal and *N* is the rms value of the noise, the total reading is  $T = \sqrt{(S^2 + N^2)}$ . In the case of noise originating in the NI 4070/4071/4072, factory calibration and <u>self-calibration</u> measure the internal noise, and the DSP subtracts the measured noise from the result to improve accuracy. Auto Zero can be used for the same purpose. The subtraction is not linear, but takes into account the nonlinear way in which noise increases measured readings.

The NI 4070/4071/4072 may sometimes appear to return noisier AC readings than other DMMs. In fact, it is quieter than most, but it appears noisy because it responds so quickly to changes in signal amplitude. It is very difficult to find an AC voltage source quiet enough to characterize the noise performance of the NI 4070/4071/4072. If readings appear too noisy, increase the measurement aperture.

## **Crest Factor**

Crest factor is determined by the following formula:

Crest Factor = (V<sub>peak</sub>/V<sub>rms</sub>)

For a sine wave, the crest factor is 1.414; for a 50% duty cycle square wave, the crest factor is 1. This specification is important because it indicates the maximum peak value of a waveform that the DMM can handle without overloading or introducing additional error. For example, given a certain DMM with an AC accuracy of 0.03% (always specified for sine waves) with an additional error of 0.2% for crest factors between 1.414 and 5, then the total error for measuring a triangular wave (crest factor = 1.73) is 0.03% + 0.2% = 0.23%.

Historically, making AC measurements with DMMs has been very frustrating because many tradeoffs exist. Traditional methods are derated for high crest factor signals. If you do not know the crest factor, it is difficult to predict the accuracy of the measurement. Also, high-frequency, low-level signals are measured poorly by most 6½ digit DMMs because of their analog techniques. These devices employ active diode rectifiers that cannot keep up effectively as frequency increases, unless they are driven very hard (for example, high amplitudes).

The method used by the NI 4070/4071/4072 is insensitive to crest factor error and capable of low-level measurements, limited primarily by noise. So while the specification allows for signal amplitudes of 1% of range, in practice the useful measurement range extends at least a decade lower.

## **Offset Errors**

Noise present on the input signal path of a DMM results in offset on the  $AC_{rms}$  function. It is *not* advisable to reduce this error by doing a subtraction operation (or null in the <u>DMM Soft Front Panel</u>) because the value displayed is the rms sum of the inputs.

As an example, assume a 100-count offset error on the 5 V range exists. This represents 0.5 mV. If an input of 50 mV<sub>rms</sub> is applied, the reading is:

Reading =  $\sqrt{(S^2 + N^2)}$ Reading =  $\sqrt{[(50 \text{ mV})^2 + (0.5 \text{ mV})^2]}$ Reading = 50.0025 mV<sub>rms</sub>

What appeared to be a huge offset error now accounts for only a 0.005% error in the measurement because of the rms conversion. If instead you use the DMM Soft Front Panel (DMM SFP) Null feature, the result is:

50 mV—0.5 mV = 49.5 mV

This result represents a 1% error.

# **DC and AC Current**

The NI 4070/4072 allow you to measure currents ranging from a few nanoamperes to an ampere.

DC Current mode and AC Current mode have three ranges each for the NI 4070/4072: 20 mA, 200 mA, and 1 A for DC current; 10 mA, 100 mA, and 1 A for AC<sub>rms</sub> current. The AC Current mode uses the same fast measurement technique as the AC Volts DC Coupled mode.

Note AC current measurements are always DC coupled and therefore always offer low settling time. Keep in mind that the range chosen needs to include both the signal range and its offset, otherwise the input can get overloaded. For a list of the available ranges, refer to <u>Related Documentation</u> for the NI 4070/4072 specifications document.

## **Shunt Resistor**

For all ranges, the current you measure flows through a stable onboard 0.5  $\Omega$  precision shunt resistor with temperature coefficient and power ratings selected to reduce <u>resistor self-heating</u> errors. For the effect of temperature changes on the accuracy of the measurements, refer to <u>Related Documentation</u> for the NI 4070/4072 specifications document and the temperature coefficient.

**Tip** The current measurement path within the NI 4070/4072 utilizes an electromechanical relay that provides very low resistance to assure a low burden voltage. While this relay has an exceptionally long life, you can take special precautions to ensure reliable operation.

Whenever possible, switch the NI 4070/4072 into the current measurement function before applying the current. Switching inductive current sources generally creates flyback voltages that stress the relay and, if done frequently, can shorten the reliability of the relay. Also, avoid interrupting the current by switching out of the current measurement function when currents are flowing through the circuit.

#### **Input Protection**

The current-measuring circuit is protected with a fuse rated at 1 A 250 V. The NI 4070/4072 can measure up to 1 A DC or 1  $A_{rms}$  with up to 2 A peak current.

If you apply higher current level to a range, the input protection circuitry of the NI 4070/4072 automatically engages, and you receive an overrange warning.

Also, keep in mind that exposing the current measurement connectors to voltage sources while the DC or AC current functions are selected may trigger the input protection circuitry or even blow the fuse. Do not apply more than 1 V to any of the ranges.

For more information on fuse replacement, refer to <u>Related</u> <u>Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

## **Low-Current Measurement Considerations**

You can use the NI 4070/4071/4072 to measure low current levels.

The NI 4071 offers more current measurement ranges than the NI 4070/4072. In the 1  $\mu\text{A}$  range of the NI 4071, you can resolve currents down to picoamperes.

Low-level measurements are susceptible to sources of error and noise that are often negligible for higher level measurements. In the low-level signals world, no material is an ideal insulator. Some materials are better insulators than others. Selection of proper cables and interconnects becomes very important.

When making low-level current measurements, noise and error sources are more likely to affect measurements in the order of  $10\mu$ A or less. Take into account the recommendations listed in the table below to ensure measurement integrity.

Error or Noise Source	Cause	Level of Induced Error	Recom
Input bias current	<ul> <li>Input bias current doubles with every 10 °C increase.</li> <li>Input bias current results in an offset error that is temperature dependent on the 1 µA–10 µA ranges.</li> </ul>	Typically 10 pA at 23 °C ambient, but it is factory calibrated to zero at that temperature.	<ul> <li>Maint ambia less t enabl remo DMM the m</li> <li>If you abova offset taking meas</li> </ul>
Leakage currents due to poor insulation	When measuring low-level currents, leakage currents in	Depends upon the resistivity of the insulator material.	Be sure that the DUT is co material appr

	insulators become relevant. Current flows between a high-impedance point and the nearby voltage sources.	Some examples include the following: • Glass Epoxy: $>10^{12} \Omega$ • Nylon: $>10^{12} \Omega$ • Polyethylene: $>10^{15} \Omega$ • Virgin Teflon: $>10^{16} \Omega$	desired test a fixture is clea
Noise currents due to triboelectrics <sup>1</sup>	Currents are generated by moving the cables because a transfer of charge occurs between the insulator and the conductor when they rub against each other.	Hundreds of pA in a polyethylene cable (for example, RG-58)	<ul> <li>Use I made polye</li> <li>If you polye be es do the</li> </ul>
Noise currents due to piezoelectrics <sup>2</sup>	Currents can be generated when the insulator is subjected to mechanical stress.	Hundreds of pA for polyethylene	<ul> <li>Rema stress insula</li> <li>Make struct espea Teflor</li> </ul>
Error currents due to contamination	Insulation resistance gets reduced with	On the order of pA to μA	<ul> <li>Selec low w such</li> </ul>

and humidity	increasing humidity and contamination. These two combined could also generate small electrochemically- induced currents.		<ul> <li>Keep mode recon maint humic espec level the ei quest</li> <li>Keep DUT clean</li> </ul>
Noise currents due to electromagnetic interference and electric fields	Surrounding equipment (motors, power cables, vibrating equipment) can induce noise currents. Moving people and charged objects near measurement setup can induce electrostatic coupling.		<ul> <li>Use s pair c</li> <li>Shieli undei</li> <li>Move and c equip the m circui</li> <li>Avoid move circui meas taken</li> <li>Use s such 8331 the B Incori at ww more these</li> </ul>
Burden voltage	For the maximum burden voltage per	Depends on the circuit being	Calculate if tr burden voltaç

	range, refer to the Related Documentation for the NI 4070/4071/4072 specifications documents.	measured	when measu the circuit of <u>Burden Volta</u> example.
Leakage currents due to external switching	External switches used for routing low level currents could be a source of leakage currents.	Depends on the switch, temperature and humidity of the environment.	<ul> <li>Cons docui to rec errors</li> <li>Refer <u>Curre</u> recor syste Maint and F condi and 5 humit switcl leaka abovt</li> </ul>

<sup>1</sup>The Triboelectric Effect can be compared to the phenomenon of static el by rubbing certain insulators together. Teflon and silver in combination, fo create a very high level of triboelectric-induced current noise.

<sup>2</sup>The Piezoelectric Effect, although well-exploited in sensors which converses pressure from sound waves or physical vibration into small voltage signal undesirable in cables and interconnects.

In addition to following these recommendations to reduce noise and errors, use software filtering and noise reduction techniques such as increasing the measurement aperture, choosing the most appropriate type of <u>DC Noise Rejection</u>, or averaging several measurements by setting the <u>Number of Averages</u> property.

Refer to Switching Current for more recommendations for systems with

switches.

## **High-Current (Up to 10 A) Measurement Considerations**

The NI 4065 and NI 4071 can measure currents up to 3 A, and the NI 4070/4072 can measure currents up to 1 A.

If you need to measure currents higher than the maximum range available, you can use the CSM-10A external shunt to measure currents up to 10 A. Refer to <u>Measuring Current</u> and to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide* for more information about how to use the CSM-10A shunt with the NI 4065 and NI 4070/4071/4072.

When measuring high current values, you could get errors due to <u>resistor</u> <u>self-heating</u>. The NI 4065 and NI 4070/4071/4072 use internal shunt resistors with low temperature coefficients and good thermal resistance. Refer to the temperature coefficients in the specifications of each device for the effect of temperature changes on the accuracy of these measurements.

The NI CSM-200mA and NI CSM-10A current shunts have excellent temperature coefficients of resistance. Refer to the <u>NI Products</u> Web site for more information on the NI CSM-200mA and NI CSM-10A current shunts.

Check if the burden voltage can affect your measurement. Refer to <u>Burden Voltage</u> for an example on how to calculate the error due to burden voltage.

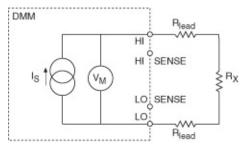
In applications where more than one current needs to be measured using the same DMM and the conditions require that the current cannot be interrupted across the load, use one of these two methods to measure the current:

- Use a break-before-make switch in multiplexer topology and place external shunts across the channels. Connect the shunts in series with the circuit under test and then measure the voltage drop across the shunts.
- Use make-before-break switches.

If the conditions allow interrupting the current flow through the circuit under test, it is still recommended to use external shunts. Switching currents above 1 A electromechanically can diminish the life of any switch. Refer to <u>Switching Current</u> for more recommendations for systems with switches.

## Resistance

The NI 4065 and NI 4070/4071/4072 make resistance measurements using a constant-current technique. A current is supplied to the resistance under test, and the DMM measures the resulting voltage as represented in the following figure.



With a known current and voltage, the DMM can determine resistance using Ohm's Law, as follows:

 $V_M = I_s R_T$ 

where  $R_T$  is the sum of all resistances

 $R_T = R_X + R_{LEAD} + R_{LEAD}$ 

Therefore, the value of  $R_x = V_M / I_s$  if  $R_{LEAD}$  is small or negligible compared to  $R_x$ .

The NI 4070/4071/4072 generates a highly-stable current source,  $I_s$ . The table below lists the value of this current by range:

Range	Test Current <sup>1</sup>	Maximum Test Voltage (Vt)	Offset Compensated Ohms Available?
100 Ω	1 mA	100 mV	Yes
1 kΩ	1 mA	1 V	Yes
10 kΩ	100 µA	1 V	Yes
100 kΩ	10 µA	1 V	No
1 MΩ	10 µA	10 V	No
10 MΩ	1 μΑ	10 V	No
100 MΩ	1 μA    10 MΩ*	10 V	No
5 GΩ	1 μA    10 MΩ*	10 V	No

<sup>1</sup>-10% to 0% tolerance

\*Refer to Measuring on the 100 MΩ Range.

All ranges except the 100 M $\Omega$  range and the 5 G $\Omega$  range (NI 4071) have greater than 10 G $\Omega$  input resistance. The 100 M $\Omega$  range and the 5 G $\Omega$  range (NI 4071) use a 10 M $\Omega$  input resistance.

Every time you run self-calibration, the current source recalibrates to an ultra-high stability 10 k $\Omega$  reference resistor. While the absolute tolerance of the current is ±5%, the recalibration process identifies the value to a sub-ppm precision level. The calculated value of resistance is corrected to the precision of the ultra-stable reference resistor, assuring accurate measurements.

The NI 4070/4071/4072 has two modes of resistance measurement: <u>2-</u> <u>wire</u> and <u>4-wire</u>. Each mode applies the same precision current to the circuit, but the difference between 2-wire and 4-wire resistance measurements is how the voltage measurement is made.

The NI 4065 generates a highly-stable current source,  $I_s$ . The table below lists the value of this current by range:

Range	Test Current <sup>1</sup>	Maximum Test Voltage (Vt)		
100 Ω	1 mA	100 mV		
1 kΩ	1 mA	1 V		
10 kΩ	100 µA	1 V		
100 kΩ	10 μΑ	1 V		
1 MΩ	5 μΑ	5 V		
10 MΩ	500 nA	5 V		
100 MΩ	500 nA    10 MΩ*	5 V		
1-10% to 0% tolerance				
*Refer to Measuring on the 100 MQ Range.				

The NI 4065 has two modes of resistance measurement:  $\frac{2 - \text{wire}}{2 - \text{wire}}$  and  $\frac{4 - 2}{2 - \text{wire}}$ . Each mode applies the same precision current to the circuit, but the

difference between 2-wire and 4-wire resistance measurements is how the voltage measurement is made.

## **2-Wire Resistance Measurements**

The 2-wire method is commonly used as it is the simplest and most straightforward method. Using the 2-wire method, you can get accurate measurements above 100 k $\Omega$  relatively easily. For lower resistance values, such as 100  $\Omega$ , the interconnecting cabling can add significant resistance which can greatly affect your measurement. Copper is the most common and is the recommended cabling. Copper has a temperature coefficient in the 3,000 ppm/°C range, which can add instability to the measurement. NI recommends the Belden 83317E cable, which has excellent shielding and insulation resistance qualities and a resistance of 39 m $\Omega$ /ft. Refer to the Belden CDT Incorporated Web site at www.belden.com for information about this cable.

When considering cabling, refer to the following example:

Assume that a test system has 50 feet of copper interconnect cable hooked to a single 100  $\Omega$  resistance, such as a remote sensor device, the cable could easily introduce a resistance of ~2  $\Omega$  because Belden 83317E has a resistance of 40 m $\Omega$ /ft and 50 ft x 40 m $\Omega$ /ft = 2  $\Omega$ . The temperature coefficient of the resistance is as follows:

 $TC = 2\Omega \times 3,000 \text{ ppm/°C} = 6 \text{ m}\Omega/°C$ 

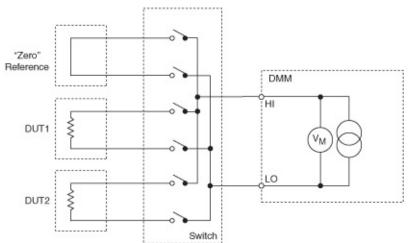
Relative to the 100  $\Omega$  resistance being measured:

 $TC = (6 \text{ m}\Omega/^{\circ}\text{C})/(100 \Omega) = 60 \text{ ppm}/^{\circ}\text{C}$ 

The error introduced by the copper not only affects the initial value of resistance measured but also introduces a temperature drift into the measurement. The drift with temperature of the copper resistance (60 ppm/°C in the example above) is much larger than the drift of the resistance ranges of the NI 4065 and NI 4070/4071/4072 (well under 10 ppm/°C). Recognize, however, that this drift might be perfectly acceptable to the particular measurement being made. Temperature drifts should be considered in the system error budget.

Sometimes the leads can be locally shorted, a measurement made, and then this "offset" and its associated TC subtracted from the subsequent 2-wire resistance measurement on the resistors under test. This technique works with careful experimental measurement practice. An outline of the methodology for this technique in the context of an automated measurement system, with programmable switching available, is as follows:

1. Short the leads as close to the resistance under test as possible. If the measurement is part of an automated switching system, dedicate a switch channel to a zero value. During the measurement cycle, close the switch to the zero reference. Refer to the following figure.



- 2. Record the offset of this zero channel.
- 3. Switch to the resistance channel you want to use.
- 4. Measure the resistance value.
- 5. Subtract the offset value from the resistance value on the selected channel. The result is the resistance reading you want.

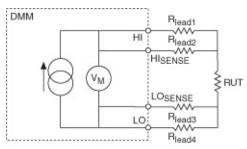
This method is subject to the following caveats:

- If the zero relay has a different contact-resistance than the rest of the relays, an error is introduced.
- If possible, you should terminate the zero channel with a cable very close in length to those cables leading to the resistance under test, matching the path length as closely as possible.
- This method does *not* correct for the lead resistance of the component you are testing.
- A time penalty occurs in the system and is associated with closing the zero relay and taking the additional measurement.
- The stability of the relay ON-resistance may limit this method to a repeatability of about  $\pm 20 \text{ m}\Omega$ .

## **4-Wire Resistance Measurements**

For precision measurements with resistances below 100 k $\Omega$ , the 4-wire mode is more accurate than the 2-wire mode. The 4-wire mode requires 4-wire switching and more cabling; however, you may decide the tradeoff is acceptable, depending upon the accuracy versus complexity requirements of your system.

The following figure shows a 4-wire resistance measurement, including lead resistance:



In 4-wire resistance measurements, current is forced through the source terminals (*HI*, *LO*). The sense terminals (*HI*<sub>SENSE</sub>, *LO*<sub>SENSE</sub>) are configured for very high impedance, and this configuration directs current through the resistance under test (*RUT*). As a result, voltage develops across *RUT* as well as across  $R_{LEAD1}$  and  $R_{LEAD4}$ . By measuring the voltage directly across *RUT* using the sense leads ( $R_{LEAD2}$ ,  $R_{LEAD3}$ ), the voltage drop of the source leads ( $R_{LEAD1}$ ,  $R_{LEAD4}$ ) is removed from the measurement path.

The current source in the NI 4065 and NI 407*x* devices, and any of the current sources used in resistance measurements, have limited voltages that they can withstand. To avoid damage to the DMM, refer to the NI Product Manuals Library Web site for the specifications document for the DMM that you are using; this document lists the maximum 4-wire lead resistance, which is the maximum resistance that can occur in the source leads ( $R_{LEAD1}$ ,  $R_{LEAD4}$ ) that connect *HI* and *LO* terminals to *RUT*.

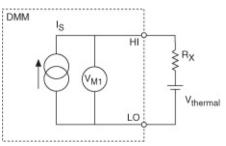
A maximum 4-wire lead resistance that is specified as *the lesser of 10%* of range or 1  $k\Omega$  implies that the maximum 4-wire lead resistance  $(R_{LEAD1} + R_{LEAD4})$  is within these limits.

For example, if you are using the 100 k $\Omega$  resistance range, 10% of this range is 10 k $\Omega$ . Therefore, the maximum 4-wire lead resistance ( $R_{LEAD1}$  +

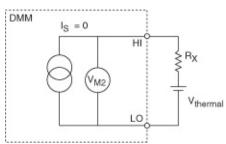
 $R_{LEAD4}$ ) is 1 k $\Omega$ .

# **Offset Compensated Ohms**

Offset Compensated Ohms is an NI 4070/4071/4072 feature provided for eliminating offset voltages in a resistance test system. Whether 2-wire or 4-wire, <u>Offset Compensated Ohms</u> applies, and the concept is the same. You have learned about the challenges of removing offset resistances from the measurement; however, Offset Compensated Ohms is different —it acts on offset voltages. The measurement involves two cycles as shown in the following figures. The following figure represents the first cycle with the current source ON:



The following figure represents the second cycle with the current source OFF:



The net result is the difference between the two measurements. Because the offset voltage is present in both cycles, it is subtracted out and does not affect the resistance calculation.

$$V_{OCO} = V_{M1} - V_{M2} = (I_S R_X + V_{THERMAL}) - V_{THERMAL} = I_S R_X$$

therefore:

$$R_X = V_{OCO}/I_S$$

## When to Use Offset Compensated Ohms

4-wire measurements provide exceptional accuracy if copper interconnects and low-thermal relays are used in the measurement system. However, there are situations when offset voltages present introduce significant errors:

- a. Switching systems using uncompensated reed relays can have offset voltages >10  $\mu$ V due to the Kovar lead material used at the device glass seal.
- b. In-circuit resistance measurements, for example, power supply conductors being measured for resistance, while the circuit is live.
- c. Measuring the on-resistance of batteries, dynamic resistance of forward biased diodes, and so on.

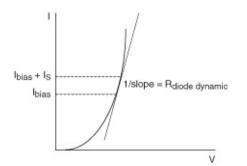
In the case of a above, often a test system is built with switching optimized for other things besides resistance measurements. For example, reed relays are common in RF test systems due to their predictable impedance characteristics and high reliability. In such a system you may want to also measure resistances. It might not be economical to add switching hardware for a few channels of resistance, and the RF relays may already be present.

In the case of b, an example would be measuring the resistance of a power supply bus cable. The resistance might be 10 m $\Omega$ . If 100 mA is flowing through this resistance, the voltage drop is:

 $V = 100 \text{ mA x } 10 \text{ m}\Omega = 1 \text{ mV}$ 

The DMM without offset compensation on the 100  $\Omega$  range interprets this as 1.05  $\Omega$  (recall from the <u>table</u> of Source Current and Maximum Test Voltages that 105  $\Omega$  corresponds to nominally 100 mV). With the NI 4070/4071/4072 and Offset Compensation, the 1 mV offset is rejected, and the correct value of resistance is returned.

In the case of c above, remember that this test only works if the diode is already forward biased. The NI 4070/4071/4072 does not supply a DC bias to the diode in Offset Compensated Ohms. The NI 4070/4071/4072 does provide the small signal displacement current, but the diode still needs to be biased. The following figure shows this diode example:



To get the dynamic resistance of the diode (or transistor) the selection of the appropriate measurement range is key. NI recommends selecting a range with a corresponding current source value 10% of the bias current level or less.

NI does not recommend using the DMM to directly measure the series resistance of cells greater than 1 V. The NI 4070/4071/4072 does not have enough voltage dynamic range to do this on the lower resistance ranges. Of course, you can use the DMM in conjunction with an external current source or load to do this.

As a general rule for measuring resistances in the presence of large DC offsets, do not violate the following formula, or the results may be erroneous:

 $V_{os} + I_s R_x = V_t$ 

where

 $V_{os}$  is the offset voltage (what you are trying to compensate out)

 $I_{\rm s}$  is the source current (dependent on range, refer to the <u>table</u> above)

 $R_{x}$  is the resistance being measured (or its upper bound)

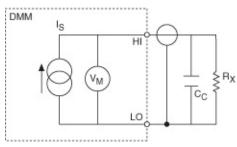
 $V_t$  is the maximum test voltage (from <u>table</u> above)

# **System Considerations for Resistance Measurements**

When measuring resistance in a system, it is important to consider the effects of cable resistance. It is also important to notice that interactions between scanning multiple resistances and system cabling can present time-dependent problems. These problems can be avoided by following these simple guidelines.

- As you scan from channel to channel, the current source must drive the voltage across the resistor to a quiescent level before a meaningful measurement can be made. If there is substantial system capacitance, this capacitance must also be charged by the current source. Starting the measurement before the capacitance is fully charged results in an erroneous measurement. For more information, refer to <u>Settling Time</u>.
- Resistance measurements up to 10 k $\Omega$  seldom encounter settling time problems, as long as the system capacitance is <500 pF and you allow a settling time of 2 ms or more.
- Settling time might need to be longer if significant dielectric absorption effects are present in the cables and switching system. Resistance values above 100 kΩ are most sensitive to cable capacitance and other dielectric effects. If dielectric absorption is suspect, find the optimum setting experimentally by increasing the settling time until the readings no longer change.

The following figure illustrates the factors affecting settling time for a resistance measurement:



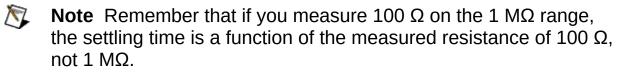
```
Settling Time = kC_CR_X
```

### where

k = the value related to accuracy required, refer to <u>Settling Time</u>

 $C_C$  = the capacitance of the cable and switching network

 $R_X$  = the resistance being measured



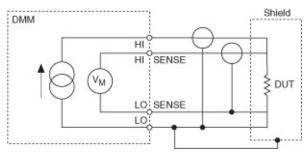
Refer to <u>DMM Measurement Cycle</u> for more information on <u>settling time</u>. Remember that the Offset Compensated Ohms function toggles the current source on and off. Excessive system capacitance due to cables, in circuit elements, and so on may affect this measurement as it affects it in a scanning system. The Belden 83317E cable has a capacitance of 35.5 pF/ft and extremely low <u>dielectric absorption</u>. Refer to the Belden CDT Incorporated Web site at <u>www.belden.com</u> for information about this cable.

# **Optimizing for High-Resistance Measurements**

The techniques required to accurately measure high resistances are somewhat different than those required for low resistances. Electrostatic noise pickup becomes a major concern. To prevent problems with noise pickup, shielding must be considered. Refer to <u>Measuring on the 100 MΩ</u> Range for more information.

### Shielding

When measuring resistances >100 k $\Omega$  proper shielding is critical. Highresistance measurements are very sensitive to environmental noise such as power line pick up, changes in electrostatic fields caused by people moving nearby, and even RF pickup. For these reasons, it is strongly encouraged to use shielded cables when measuring high resistances. For 2-wire measurements the shield should be tied to the LO terminal. For 4-wire measurements, there are two pairs of shielded cables. The first pair should be tied to HI and LO (shield to LO), and the second pair to HI SENSE and LO SENSE (shield to LO SENSE). Refer to the figure below:



# **Frequency/Period**

The NI 4070/4071/4072 can measure periodic signal frequencies, up to 500 kHz, from a variety of signal sources, ranging from millivolts to 300  $V_{rms}$  (NI 4070/4072) or 700  $V_{rms}$  (NI 4071).

The NI 4070/4071/4072 measures frequency by counting the number of zero-crossing rising edges of the input signal, using an onboard 28.8 MHz timebase.

```
Frequency (Hz) = timebase (Hz) x Ns / Nt
```

Period = 1 /Frequency (Hz)

where

timebase =  $28.8 \times 10^6$  Hz

*Ns* = number of rising edges detected in the measurement window

Nt = number of timebase clock periods between the first and the last rising edge

To measure a signal of frequency f in Hz, the DMM needs a minimum aperture of (2/f) s. The resolution of the frequency measurement is independent of the input signal frequency and depends only on how long the NI 4070/4071/4072 is able to look at the signal. A longer aperture enables a finer frequency resolution.

Frequency Resolution (ppm) =  $10^6$  (ppm) x 4 / [timebase (Hz) x aperture (s)]

where *timebase* =  $28.8 \times 10^6$  Hz.

For example, the aperture setting of 100 ms allows you to measure a signal of a minimum frequency of 20 Hz with a resolution of 1.4 ppm.

The accuracy of the frequency measurement is directly related to the absolute accuracy of the 28.8 MHz oscillator used on the NI 4070/4071/4072. The accuracy of frequency measurement is 25 ppm including temperature and time drift. In addition, the amount of noise that couples with the signal can affect the accuracy. The NI 4070/4071/4072 frequency measurement circuit has a hysteresis circuit that rejects noise up to 5% of the AC V range being used.

For example, if you are measuring TTL level signals, use the 5 V AC

range (10  $V_{pk}$ ). The frequency measurement circuit offers hysteresis of 250 mV in this case, which means you can have up to ±125 mV noise glitches superimposed on top of the signal and still be able to measure frequency accurately before it reaches the frequency measurement comparator circuit.

The minimum peak-to-peak signal amplitude required to measure frequency is 10% of the AC V range being used. In the previous example, a minimum of 500 mV (peak-to-peak) is required by the frequency measurement circuit to work correctly. Notice that for the 300 V AC range, the hysteresis is 8% of range (25 V), while the minimum peak-topeak signal amplitude required is 17% of range (50 V).

As signals approach the 500 kHz bandwidth of the AC V path, the minimum peak-to-peak signal amplitude requirement increases by approximately a factor of three.

AC V Range	Maximum Peak- to-Peak Signal Voltage Allowed	Minimum Peak-to- Peak Signal Amplitude Required	Hysteresis
50 mV	200 mV	5 mV	2.5 mV
500 mV	2 V	50 mV	25 mV
5 V	20 V	500 mV	250 mV
50 V	200 V	5 V	2.5 V
300 V (NI 4070/4072 only)	450 V peak and <300 V <sub>rms</sub>	50 V	25 V
700 V (NI 4071 only)	1000 V peak and <700 V <sub>rms</sub>	50 V	25 V

Another way to measure frequency is to perform <u>waveform acquisitions</u> and then to use the signal processing functions in the ADE to extract the frequency. This method of measuring frequency also allows you to extract frequency information based on amplitude and hysteresis.

# Diode

The NI 4065 and NI 4070/4071/4072 can excite a DUT with a constant current source and read the resulting voltage drop using a 10 V DC range. Diode mode is useful for testing p-n junctions, LEDs, and zener diodes. The default current excitation is 1 mA, and a voltage up to 4.5 V (NI 4070/4072), 4.0 V (NI 4071), or 3.5 V (NI 4065) can be measured with this setting. You can also set the current source to 1 uA, 10 uA, or 100 uA for the NI 4070/4071/4072 and 100 uA for the NI 4065, in which case voltage up to 10 V can be measured. Refer to niDMM Configure Current Source or niDMM ConfigureCurrentSource for more information about how to configure the current source.

# **Temperature Measurements**

The NI 4065/4070/4071/4072 can measure temperature using common temperature transducers. The three most commonly used transducers for temperature are thermocouples, resistance temperature detectors (RTDs), and thermistors. Compatible thermocouples and RTDs are available from National Instruments and compatible thermistors are available from Omega.

The following table illustrates some of the capabilities and limitations of these sensors. Use this table as a reference for choosing the right sensor for your temperature measurement application.

Sensor	Advantages	Disadvantages
<u>Thermocouples</u>	wide range, fast response, inexpensive	require reference temperature, nonlinear
<u>RTDs</u>	rugged, accurate	slow response, lead resistance, nonlinear, self-heating
<u>Thermistors</u>	repeatable, fine resolution, low current, fast response	narrow range, nonlinear

The following table lists NI-DMM supported device/sensor combinations:

Device	Thermocouple Support
<u>NI 4070/4071/4072/4065</u>	<ul> <li>2-wire</li> <li>ITS-90 polynomial scaling</li> <li>Presets for types J, K, N, T, E, R, S, and</li> </ul>

1	

### Measurement Range, Resolution, and Options

NI-DMMs perform a measurement appropriate to the temperature transducer type (DC voltage for thermocouples, resistance for RTDs or thermistors), and convert this reading into degrees Celsius. See <u>thermocouples</u>, <u>RTDs</u>, and <u>thermistors</u> for specific cabling details.

When configuring a temperature transducer measurement, the user must specify the range and resolution of the underlying voltage or resistance measurement while configuring the DMM. The following range settings are recommended for optimal accuracy, speed, and range of the supported transducers. Users may wish to select a different range for measurements at extreme temperatures or when using custom transducer types.

Transducer	<b>Recommended Range</b>
Thermocouple	100 mV
100 Ω RTD	1 kΩ
1k Ω RTD	10 kΩ
1kΩ to $10$ kΩ Thermistor	100 kΩ

Other measurement options, such as Auto Zero, Offset Compensated Ohms, Settling Time, and Aperture Time still apply to the underlying voltage or resistance measurement where applicable.

# Thermocouples

Thermocouples consist of a pair of dissimilar metals that meet at a contact point, which produces a small, open-circuit voltage that corresponds to temperature. This thermoelectric voltage is known as Seebeck voltage and is nonlinear with respect to temperature.

This voltage is converted to temperature using tables of coefficients and the following polynomial scaling function:

$$t_{90} = \sum_{i=0}^{n} D_i (\varepsilon)^i$$

where  $t_{90}$  is the temperature in degrees Celsius, *E* is the voltage in millivolts, and  $D_i$  is the coefficient.

The NI 4065/4070/4071/4072 support temperature measurements with J, K, N, T, E, R, S, and B type thermocouples, The driver software contains all necessary coefficient tables to perform the ITS-90 polynomial scaling.

Thermocouple types differ in composition and accurate range as illustrated in the following table:

Thermocouple Type		Negative Conductor	Temperature Range (°C)	Extended Temperature Range (°C)
J	Iron	Constantan	-150 to 1200	–210 to –150
К	Chromel	Alumel	-100 to 1200	–200 to –100
Ν	Nicrosil	Nisil	-100 to 1300	-200 to -100
Т	Copper	Constantan	-100 to 400	–200 to –100
E	Chromel	Constantan	-150 to 1000	–200 to –150
R	Platinum- 13% Rhodium	Platinum	300 to 1760	–50 to 300
S	Platinum- 10% Rhodium	Platinum	400 to 1760	–50 to 400
В	Platinum	Rhodium	1100 to 1820	400 to 1100

### **Reference Junction**

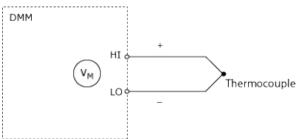
Thermocouple measurements require a user-specified fixed reference junction temperature. This is also referred to as the "cold-junction compensation" or "CJC" temperature. If the user does not specify a reference junction temperature, a default of 25 °C is assumed.

NI-DMM provides the Measure Temperature (Thermocouple) example, which you can find by using the shortcut at **Start»All Programs»National Instruments»NI-DMM»Examples**.

In many applications, the reference junction temperature is measured by a separate temperature sensor (typically an RTD or thermistor) to improve thermocouple measurement accuracy.

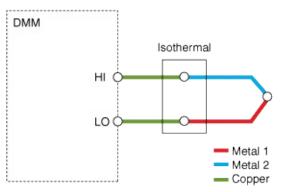
## Cabling

Thermocouples are cabled using the HI and LO connectors of the DMM. The polarity of the thermocouple leads is critical for correct thermocouple measurements.



You must use a thermocouple adapter to connect a thermocouple to your DMM.

Thermocouples require some form of temperature reference to compensate for unwanted parasitic thermocouples. This process is called cold-junction compensation.



### **Underlying DMM Measurement**

To measure temperature with any thermocouple, the DMM internally performs a DC Voltage measurement with the range, resolution, timing, and other measurement options that have been specified by the user. The resulting voltage is then converted to degrees Celsius by software using ITS-90 polynomial scaling.

When configuring a temperature transducer measurement, the user must specify the range and resolution of the underlying voltage or resistance measurement while configuring the DMM. The recommended range for thermocouples is 100 mV

Note For more information on taking thermocouple temperature measurements, refer to the NI Developer Zone document, <u>Taking Thermocouple Temperature Measurements</u>.

# **Resistance Temperature Detector (RTDs)**

An RTD, or Resistance Temperature Detector, is a temperature sensing device with resistance that increases with temperature. An RTD is usually constructed with wire coil or deposited film of pure metal. RTDs can be made of different metals and have different nominal resistances, but the most popular RTD is platinum and has a nominal resistance of 100  $\Omega$  at 0  $^\circ\text{C}$ .

Numerous types of RTDs exist, and they are typically defined by their material, their nominal resistance, and their temperature coefficient of resistance (TCR). The TCR, or  $\alpha$ , of an RTD is the average temperature coefficient of resistance of the RTD from 0 to 100 °C and is the most common method of specifying the behavior of an RTD. The TCR for platinum RTDs is determined by the Callendar-Van Dusen equation.

The Callendar-Van Dusen equation is as follows:

Temperatures below 0 °C:

 $R_T = R_0[1 + A \times T + B \times T^2 + C \times T^3 \times (T - 100 \text{ °C})]$ 

Temperatures above 0 °C:

 $R_T = R_0 [1 + A \times T + B \times T^2]$ 

T = temperature in degrees Celsius

 $R_T = RTD$  resistance at temperature T

 $R_0 = RTD$  nominal resistance at 0 °C

A, B, and C = coefficients listed in the following table.

The following table lists common platinum RTD types and standards supported in NI-DMM. Notice that there are some shared standards. The TCR and the Callendar-Van Dusen coefficients are more important than the standards. NI-DMM also supports user-specified A, B, and C coefficients through the custom RTD type if none of the presets below match the transducer.

Standards	Material	TCR (α)	Tynical	Callendar- Van Dusen	Notes

			R <sub>0</sub> (Ω)	Coefficient	
IEC-751 DIN 43760 BS 1904 ASTM-E1137 EN-60751	Platinum	.003851	100 Ω 1000 Ω	A = 3.9083 × 10 <sup>-3</sup> B = - 5.775×10 <sup>-7</sup> C = - 4.183×10 <sup>-12</sup>	Most common RTDs
Low-cost vendor compliant RTD*	Platinum	.003750	1000 Ω	A = $3.81 \times 10^{-3}$ B = $-$ $6.02 \times 10^{-7}$ C = $-6.0 \times 10^{-12}$	Low-cost RTD
JISC 1604	Platinum	.003916	100 Ω	A = 3.9739 × 10 <sup>-3</sup> B = - 5.870×10 <sup>-7</sup> C = -4.4 ×10 <sup>-12</sup>	Used primarily in Japan
US Industrial Standard D-100 American	Platinum	.003920	100 Ω	A = $3.9787 \times 10^{-3}$ B = $-$ 5.8686×10 <sup>-7</sup> C = $-4.167 \times 10^{-12}$	Low-cost RTD
US Industrial Standard American	Platinum	.003911	100 Ω	A = 3.9692 × 10 <sup>-3</sup> B = - 5.8495×10 <sup>-7</sup> C = -4.233 ×10 <sup>-12</sup>	Low-cost RTD
ITS-90	Platinum	.003928	100 Ω	A = 3.9888 × 10 <sup>-3</sup> B = –	The definition of temperature

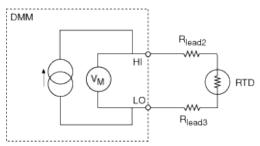
	$5.915 \times 10^{-7}$ C = -3.85 $\times 10^{-12}$
*No standard. Check the TCR.	

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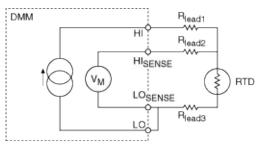
**Note** For more information on taking temperature measurements with an RTD, refer to the NI Developer Zone document, <u>Measuring</u> <u>Temperature with an RTD or Thermistor</u>.

## Cabling

2-Wire RTD measurements are wired using the HI and LO connectors of the DMM:



To use a 3-Wire RTD configuration in a 4-wire RTD, jumper the negative end of the current excitation connection to the negative end of the voltage measurement connection. This configuration decreases the effect of lead resistance on the measurement, however,  $R_{lead3}$  will still contribute some error, depending on its resistance:

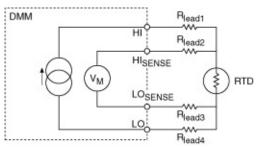


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**Note** You must configure your NI-DMM using a 4-wire connection for 3-wire measurements.

4-Wire RTD measurements are wired using the HI, LO,  $HI_{SENSE}$ , and  $LO_{SENSE}$  connectors of the DMM. This configuration minimizes the

### effects of lead resistance:



### **Underlying DMM Measurement**

To measure temperature with an RTD, the DMM performs a 2-Wire or 4-Wire resistance measurement with the range, resolution, timing, and other measurement options that have been specified by the user. The resulting resistance is then converted to degrees Celsius by software using the Callendar-Van Dusen equation and  $R_0$ , A, B, and C coefficients.

When configuring a temperature transducer measurement, the user must specify the range and resolution of the underlying voltage or resistance measurement while configuring the DMM. The recommended range for a 100  $\Omega$  RTD is 1 k $\Omega$  and the recommended range for a 1 k $\Omega$  RTD is 10 k $\Omega$ .

### Self-Heating

There is an  $I^2R$  power dissipated by the RTD that causes self-heating. Self-heating will actually change the resistance of the RTD, causing error in the measurement. RTDs are prone to self-heating because they require current excitation. The effects of self-heating can be minimized by supplying lower excitation current.

Typically, a *dissipation constant* is provided in RTD specifications. This number relates the power required to raise the RTD temperature by one degree of temperature. Thus, a 25-mW/°C dissipation constant shows that if  $I^2R$  power losses in the RTD equal 25 mW, then the RTD will be heated by 1 °C.

The dissipation constant is usually specified under two conditions free air and a well-stirred oil bath. This is because of the difference in capacity of the medium to carry heat away from the device. The self-heating temperature rise can be found from the power dissipated by the RTD and the dissipation constant from

$$\Delta T = \frac{P}{P_D}$$

where

DT = temperature rise because of self-heating in °C

P = power dissipated in the RTD from the circuit in W  $P_D$  = dissipation constant of the RTD in W/°C

Refer to **Resistor Self-Heating** for more information.

# Thermistors

A thermistor is a piece of semiconductor made from metal oxides, pressed into a small bead, disk, wafer, or other shape, heated at high temperatures, and coated with epoxy or glass.

Like RTDs, Thermistors have a resistance that varies nonlinear with respect to temperature. Unlike RTDs, thermistors have a higher resistance (anywhere from 2,000 to 10,000  $\Omega$ ) and a much higher sensitivity (~200  $\Omega$ /°C). However, thermistors are generally used only up to the 300 °C temperature range.

NI-DMM scales the resistance of a thermistor to a temperature using the Steinhart-Hart thermistor equation:

 $\frac{1}{\tau} = A + B(In(R)) + C(In(R))^3$ 

where T is the temperature in Kelvins, R is the measured resistance, and A, B, and C are constants provided by the thermistor manufacturer.

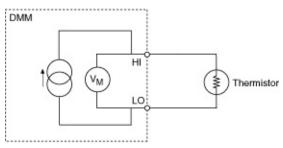
Because thermistors have high resistance, lead-wire resistance does not affect the accuracy of the measurements. Unlike RTDs, 2-wire measurements are adequate.

NI 4065/4070/4071/4072 devices support the following sensors from Omega's 44000-Series. NI-DMM also supports user-specified A, B, and C coefficients through the custom thermistor type if none of the presets below match the transducer.

Sensor	Nominal Resistance (25 °C)	Steinhart-Hart Coefficients
Omega 44004	2.25k	A =1.468e-3 B =2.383e-4 C = 1.007e-7
Omega 44006	10k	A = 1.032e-3 B = 2.387e-4 C = 1.580e-7
Omega 44007	5k	A = 1.285e-3 B = 2.362e-4 C = 9.285e-8

## Cabling

Thermistor measurements are wired using the HI and LO connectors on the DMM:



### **Underlying DMM Measurement**

To measure temperature with a thermistor, the DMM performs a 2-wire resistance measurement with the range, resolution, timing, and other measurement options that have been specified by the user. The resulting resistance is then converted to degrees Celsius by software using the Steinhart-Hart equation and A, B, and C coefficients.

When configuring a temperature transducer measurement, the user must specify the range and resolution of the underlying voltage or resistance measurement while configuring the DMM. The recommended range for a 1 to  $10k\Omega$  thermistor is  $100 \ k\Omega$ 

# **Waveform Acquisitions**

The following sections cover optimizing waveform acquisitions for the NI 4070/4071/4072.

- <u>Waveform Acquisition Defaults</u>
- Waveform Acquisition Measurement Cycle
- Analog Bandwidth
- <u>Nyquist Theorem</u>
- Overranging
- Input Coupling
- Sample Rate
- DC Noise Rejection for Waveforms
- <u>Transient Measurement Considerations</u>
- <u>Current Waveforms</u>

For more information about acquiring waveforms on the NI 4070/4071/4072, refer to <u>Acquiring Waveforms</u>.

# **Waveform Acquisition Defaults**

The following table lists the default waveform acquisition settings for the NI 4070/4071/4072. For more information on a particular attribute, including how to configure a non-default setting, refer to <u>Features</u>.

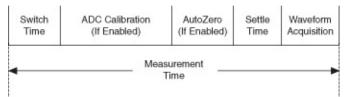
Waveform Function	Auto Zero	ADC Calibration	DC Noise Rejection
Voltage	OFF	OFF	Normal
Current	OFF	OFF	Normal

# Waveform Default Settling Times

Function	Settling Time
V (100 mV–10 V)	1 ms
V (100 V, 300 V) (NI 4070/4072 only)	2 ms
V (100 V, 1000 V) (NI 4071 only)	5 ms
	100 µs

# **Waveform Acquisition Measurement Cycle**

The NI 4070/4071/4072 waveform measurement cycle is made up of several phases: settling time, waveform acquisition phase, Auto Zero, and ADC calibration. Refer to the figure below for relative timing of these phases. The length of the waveform measurement phase is determined by the selected sample rate and number of points. Generally the settling time is selected by the device driver based on the specified function and range. This value can also be independently controlled. Refer to Configuring Measurement Timing for more information.



An internal switch time is required to configure the analog circuitry of the NI 4070/4071/4072 for the next measurement. Default settling times also precede both <u>ADC calibration</u> and <u>Auto Zero</u>. These settling times are not user programmable and are optimized in the design.

When you enable ADC calibration, gain drift errors are removed from the waveform data. At higher speeds, the lower resolution measurements make ADC calibration unnecessary.

Auto Zero removes offset from the waveform data. An Auto Zero measurement is taken and stored. This offset is subtracted from each point.

# Overranging

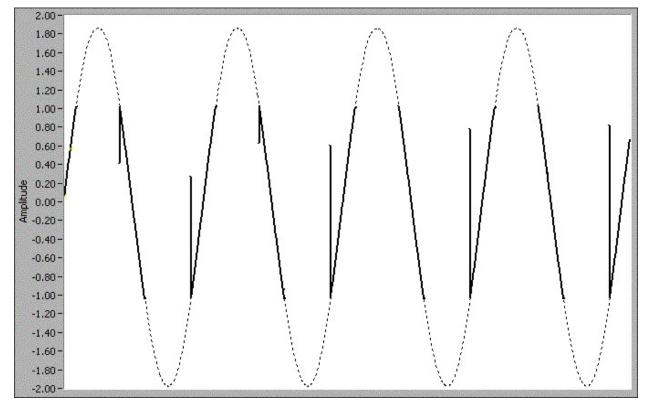
The NI 4070/4071/4072 sigma-delta modulator has a characteristic overload recovery behavior that you must be aware of when selecting the range of measurement for waveform acquisition. Select the input range carefully, so that the acquired signals, including instantaneous peaks, are within range at all times. For instance, when the NI 4070/4071/4072 is configured for the 10 V input range, the signal must remain within +/-10.5 VDC (21  $V_{P-P}$ ). Signals applied to the NI 4070/4071/4072 that are outside of the input range cause the sigma-delta modulator within the ADC to enter into an overrange condition. In this condition, the software returns the value of NaN (Not a Number) for all the measurements during the time that the signal is outside the range. During recovery from an overrange condition, the NI 4070/4071/4072 may return several invalid data points once the signal recovers to within the range limits. To prevent the ADC from being saturated, it is imperative that the signal being measured is always within the input range limits. When the input signal is outside the limits, the niDMM Read Waveform and niDMM Fetch Waveform functions return an overrange warning. If your application encounters this warning, you should consider your data to be corrupted, and you should acquire the data again with the appropriate input range selections.

We recommend starting with the highest available range first before settling on the range of measurement. By doing this, it is possible to get a "preview" of the measured waveform while avoiding transient overloads caused by slew rate limitations. This is also a good way to determine the signal peaks before zooming in with a more sensitive range.

For the NI 4070/4071/4072, the frequency response is similar across all ranges, so there is no loss of signal integrity by using this approach. If the signal is small, some resolution is lost. However, once you identify this small signal and loss of resolution, you can carefully select a more sensitive range.

The following figure shows the NI 4070/4071/4072 waveform acquisition overrange behavior. The dotted line represents the actual voltage waveform signal at the input terminals, and the solid line represents the data returned by a waveform acquisition using an NI 4070/4071/4072 in 1 V range. The discontinuities in the solid line waveform represent NaN

values in the data, and the spikes in the solid line represent the invalid data as the signal returns to the range limit.



# Sample Rate

Sample rate is the rate at which a signal is sampled by an ADC. A higher sample rate captures more waveform details while a sample rate that is too low can distort the waveform.

The available sample rates (r) correspond to the following equation:

r = (1.8 MS/s)/y

where  $y = 1, 2, 3, ... 1.8 \times 10^5$ .

### Waveform Acquisition Time

The minimum and maximum aperture times for waveform acquisitions are 8.89  $\mu$ s and 149 s, respectively. To determine if your settings meet the required time, use the following formula:

8.89 μs < *n/r* < 149 s

where

*n* equals the number of samples

r equals the rate

Note The available sampling rates are r = (1.8 MS/s)/y, where  $y = 1, 2, 3, \dots 1.8 \times 10^5$ .

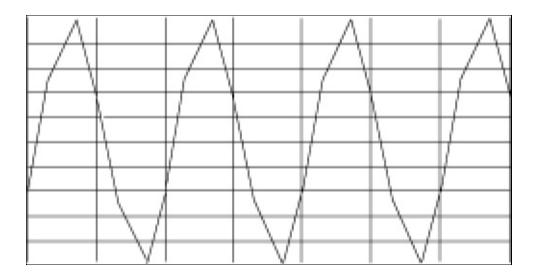
For example, if you attempt to acquire two samples at a rate of 1.8 MS/s, the result is:

2/1,800,000 S/s = 1.11 µs

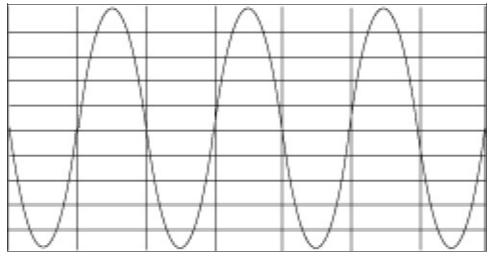
1.11  $\mu$ s is less than the minimum aperture time, and the driver returns an error. Therefore, you must acquire a minimum of 16 samples at the rate of 1.8 MS/s.

Note The record length corresponds to the aperture time.

The figure below illustrates a 100 kHz sine wave sampled at 500 kS/s:



The figure below shows the same sine wave sampled at 1.8 MS/s:



The faster rate digitizes 18 points per cycle of the input signal compared with 5 points per cycle with the slower ADC. In this example, the higher sample rate more accurately captures the waveform shape as well as frequency. This process is called over-sampling and can greatly improve the quality of the waveform measurement. The NI 4070/4071/4072 allows for 6 times over-sampling when acquiring a voltage waveform at the limit of its analog bandwidth of 300 kHz or when acquiring a current waveform at the limit of 400 kHz.

When performing a waveform acquisition, select a sampling rate that observes the <u>Nyquist Theorem</u>. Excessive over-sampling has tradeoffs. First, excessive over-sampling may give you more data than you need, unnecessarily consume processor resources, and slow the display.

Second, additional noise becomes apparent, because the noise performance of the NI 4070/4071/4072 improves as your sampling rate decreases.

Selecting a sampling rate is typically easy to determine. For example, 44.1 kHz and 48 kHz are standard sample rates for audio signals. The NI 4070/4071/4072 can sample these rates at 45 kS/s and 50 kS/s, respectively, while 24 kS/s is available for low-bandwidth audio applications. Most mid-bandwidth applications, such as audio, can benefit from the use of <u>DC Noise Rejection</u> to reduce noise and improve frequency response.

The NI 4070/4071/4072 can make very-high-resolution low-distortion audio measurements, but it does not have a low-pass filter lower than the bandwidth limitation to provide the alias protection of most audio products. To obtain the flattest response and alias protection with the NI 4070/4071/4072, sample at the maximum rate of 1.8 MS/s and postprocess (filter and decimate) in software. You can use the Analysis functions in LabVIEW or CVI to filter the acquired signal.

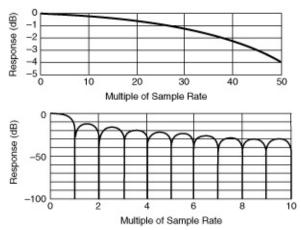
# **DC Noise Rejection for Waveforms**

The DC Noise Rejection feature that can reduce noise in DC measurements in DMM mode can also be used to alter the noise and frequency response of waveform acquisitions. Three settings of the DC Noise Rejection parameter are available: normal, second order, and high order. You can specify the noise rejection settings using a property node, as for DMM-mode readings.

Only Normal DC Noise Rejection is available for sampling rates above 200,000 S/s.

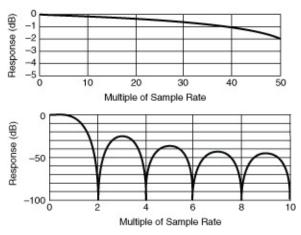
### Normal

Normal DC Noise Rejection gives rise to notches in the frequency response at multiples of the sampling rate, and the response is attenuated by 4 dB at half the sampling rate, in addition to any attenuation present at the maximum sampling rate of 1.8 MS/s. For example, with a selected sampling rate of 1 kS/s, response is down 4 dB at 500 Hz, shown in the first following graph, and is 0 at multiples of 1 kHz as shown in the second graph.



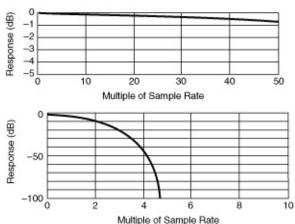
### Second Order

Second order DC Noise Rejection gives rise to notches in the frequency response at even multiples of the sampling rate, and the response is attenuated by 1.9 dB at half the sampling rate, in addition to any attenuation present at the maximum sampling rate of 1.8 MS/s. For example, with a selected sampling rate of 1 kS/s, response is down 1.9 dB at 500 Hz, shown in the first following graph, and is 0 at multiples of 2 kHz as shown in the following graph.



### **High Order**

High order DC Noise Rejection gives rise to high attenuation to frequencies above about 4 times the sampling rate, and the response is attenuated by 0.7 dB at half the sampling rate, in addition to any attenuation present at the maximum sampling rate of 1.8 MS/s. For example, with a selected sampling rate of 1 kS/s, response is down 0.7 dB at 500 Hz, shown in the first following graph, and is very small at frequencies above 4 kHz as shown in the second following graph:



## **Other Considerations**

The default DC Noise Rejection setting is Normal, and it gives the lowest noise at very low frequencies. However, it does not reject out-of-band signals very well and has considerable attenuation at half the sample rate. It also yields a non-flat noise spectrum due to the notches at multiples of the sample rate. Second order DC Noise Rejection gives the lowest overall noise over a broad range of sampling rates, roughly from 500 S/s to 100 kS/s. It does a better job rejecting out-of-band signals, while reducing in-band attenuation, and it yields a flat noise spectrum. High-order DC Noise Rejection offers the flattest in-band frequency response and is useful for rejecting strong out-of-band noise signals. It also yields a flat noise spectrum. However, it yields higher overall noise than second order DC Noise Rejection.

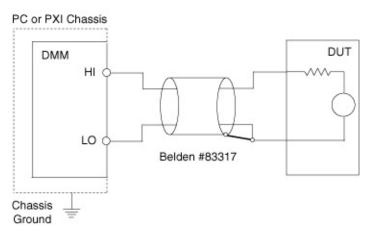
# **Transient Measurement Considerations**

## Cabling

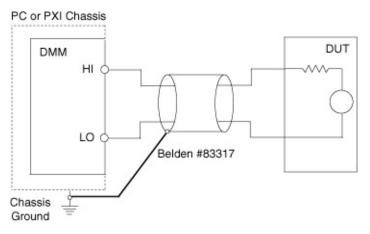
When using the NI 4070/4071/4072 to acquire waveforms, choose your connecting cable carefully. Any unshielded cable or test leads can pick up common electromagnetic and electrostatic interference which corrupts waveform measurements and introduces spurs in the frequency domain. Shielded coaxial cables are often used for waveform measurement. You can use a female-BNC-to-dual-banana-plug adapter, such as Pomona part number 1269, to easily connect the NI 4070/4071/4072 inputs to signal sources using coaxial shielded cable. National Instruments recommends the Belden 83317E shielded cable. Refer to the Belden CDT Incorporated Web site at www.belden.com for information about this cable. The Belden 83317E shielded cable works well for DMM measurements within the 300 kHz bandwidth (3 dB) of the NI 4070/4071/4072 and in situations where BNC connectivity is not required.

There are two alternative ways to connect the shield. If high frequency (> 1 kHz) common-mode AC signals are present, better results can be obtained if the shield is connected to the DMM LO terminal. If no common-mode AC signal is present or if the common-mode AC signal is low (< 100 mV), then connecting the shield to PXI chassis ground is preferable. The following figures show the DMM connected to a device under test (DUT) with the Belden 83317E cable.

As shown in the figure below, the best HI signal shielding results with a common-mode AC signal > 1 kHz. The shield potential must remain within 42  $V_{AC/DC}$  of LO:



As shown in the figure below, good shielding results if common-mode AC signals are less than 100 mV, and the shielding is safest if a large DC common-mode voltage is present.



**Caution** Always observe proper safety practices when connecting to signals. Be aware that if the LO signal is connected to a source of hazardous voltage (either AC or DC) then any exposed BNC connector shells or shields connected to this voltage will also be at this hazardous voltage.

### **Slew Rate Limitations**

The NI 4070/4071/4072 can measure almost any signal within its 300 kHz bandwidth. However, some signals may have enough high-frequency energy to introduce significant distortion. In general, the rate of change of the input signal voltage or current, also known as its slew rate, should stay below the following limits to avoid excessive distortion:

Input Range	Maximum Slew Rate
300 V (NI 4070/4072 only), 1000 V (NI 4071 only)	2000 V/µs
100 V	200 V/µs
10 V	20 V/µs
1 V	2 V/μs
100 mV	0.4 V/μs
1 A	8 A/μs
200 mA	0.8 A/µs
20 mA	0.8 A/µs

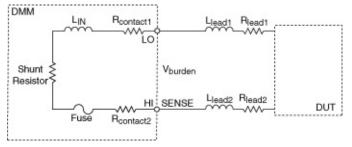
If you suspect your slew rate may be too high, you can switch to a higher range to see if the waveform shape changes significantly.

#### **Current Waveforms**

The NI 4070/4071/4072 can acquire current waveforms at frequencies up to 400 kHz. At high frequencies, the apparent burden voltage could increase from that listed in the specifications due to internal inductance.

For the maximum burden voltage per range in AC current, refer to <u>Related Documentation</u> for the specifications documents for the DMMs.

Apparent burden voltage is even higher when using long cable runs, which add more inductance and resistance. Minimize cable length or use a shunt resistor local to the DUT if wide bandwidth current waveform acquisition is desired. The following figure shows the burden voltage effect due to inductance:



For more information about burden voltage, refer to **Burden Voltage**.

# NI 4071

The NI 4071 DMM for the PXI bus has a 7½ digit capability for the resistance and DCV modes and a 6½ digit capability for all other modes. The NI 4071 has a 1000 V capability and can acquire waveforms at 1.8 MS/s. For more information about the NI 4071 specifications, refer to Related Documentation for the NI 4071 specifications document.

This topic contains the following subsections:

- Interconnects and Cables
- <u>Operation</u>
- <u>Replacing the Fuse</u>
- Calibrating the NI 4071

#### **Interconnects and Cables**

The front of the NI 4071 module has five connectors—four banana jacks and one 9-pin mini–circular DIN connector. The four banana jack connectors are high-voltage, safety-agency approved signal connectors. The 9-pin DIN connector labeled AUX I/O is a digital signal connector, which carries triggers and SCXI communication signals. For an illustration of the front panel connectors and wiring instructions, refer to <u>Front Panel Connections</u> topic for the NI 4071.

The input connectors on the NI 4071 are gold-plated, low-thermal copper for best low-voltage performance. The insulator material is a Lexan compound, optimized for low leakage over the full environmental operating range.

For use with the NI 4071, NI recommends selecting a cable with characteristics similar to the Belden 83317E; refer to the Belden CDT Incorporated Web site at <u>www.belden.com</u> for information about this cable.

Tape-wrapped polytetrafluoroethylene (PTFE) insulation guarantees low leakage. Copper conductors with silver plating perform very well for low-voltage measurements because of their low thermal characteristics. Use a cable with at least 90% shielding effectiveness.

Type of Insulator	AWG	Conductor Material	Resistance per Foot	Capacitance per Foot
TFE	26	Silver-plated copper, stranded	39 mΩ	35.5 pF

### Operation

The NI 4071 can operate as a DMM and can <u>acquire waveforms</u> up to 1.8 MS/s. The following table lists the functions and ranges supported by the NI 4071 while in DMM mode:

DMM Function	Ranges	
DC Voltage	100 mV, 1 V, 10 V, 100 V, 1000 V	
AC Voltage	50 mV, 500 mV, 5 V, 50 V, 700 V	
DC Current*	1 $\mu$ A, 10 $\mu$ A, 100 $\mu$ A, 1 mA, 10 mA, 100 mA, 1 A, 3 A	
AC Current*	100 µA, 1 mA, 10 mA, 100 mA, 1 A, 3 A	
2-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ, 10 MΩ, 100 MΩ, 5 GΩ	
4-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ, 10 MΩ	
Diode	10 V at 1 μA / 10μA / 100μA; 4.0 V at 1 mA	
Frequency/Period	50 mV, 500 mV, 5 V, 50 V, 700 V	
* To measure current outside of the normal range on the NI 4071, you must use a current shunt module (CSM). Refer to the <u>Measuring Current</u> section for more information.		

The following table lists the functions and ranges supported for waveform acquisitions:

Waveform Function	Ranges	Coupling
Voltage Waveform	100 mV, 1 V, 10 V, 100 V, 1000 V	AC or DC
Current Waveform*	100 µA, 1 mA, 10 mA, 100 mA, 1 A, 3 A	DC

\* To measure current outside of the normal range on the NI 4071, you must use a current shunt module (CSM). Refer to the <u>Measuring Current</u> section for more information.

#### **Additional Features**

- <u>Self-Calibration</u>
- <u>Auto Zero</u>
- <u>Configuring Auto Range</u>
- Offset Compensated Ohms
- ADC Calibration
- Input Resistance

- Configuring Measurement Timing
- Aperture Time
- DC Noise Rejection
- <u>Waveform Acquisitions</u>
- Single Point Acquisitions
- <u>Generating Measurement Complete</u>
- Scanning Switch Modules

#### **Replacing the Fuse**

The NI 4071 is equipped with a F 3.15 A 250 V Fast–Acting fuse designed to help protect the DMM and your test system. For instructions on replacing the fuse, refer to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

### Calibrating the NI 4071

Calibration maximizes the accuracy of a DMM. To ensure accuracy, you must perform calibration. NI recommends that you externally calibrate every two years. Refer to the <u>self-calibration</u> or <u>ADC calibration</u> sections to internally calibrate the NI 4071. Refer to the *NI 4071 7½–Digit FlexDMM Calibration Procedure* at the <u>NI Calibration Solutions</u> Web site for information on externally calibrating the NI PXI-4071. For information on calibrating the NI 4071 using National Instruments Calibration Executive, refer to the <u>NI Calibration Solutions</u> Web site. All NI measurement devices receive NIST-traceable calibration before shipping.

## **Front Panel Connections**

Move the mouse over the text to view the wiring diagrams for the NI 4071, and click for additional information.

DC Voltage

AC Voltage

DC Current

AC Current

2-Wire Resistance

4-Wire Resistance

Voltage Drop Across a Diode

**Frequency/Period** 

Voltage Waveform

Current Waveform

**SCXI** Communication

**Triggering** 



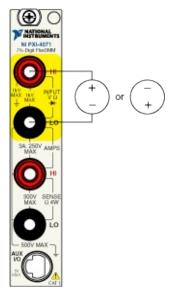
Temperature (Thermocouple)

Temperature (2-wire RTD)

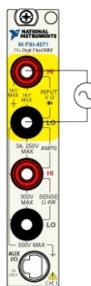
Temperature (4-wire RTD)

Temperature (Thermistor)

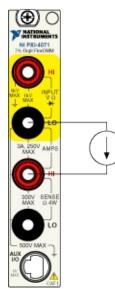
## **DC Voltage**



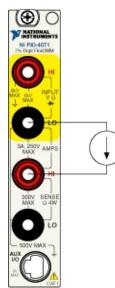
## AC Voltage



### **DC Current**

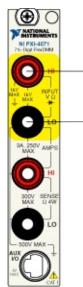


### **AC Current**

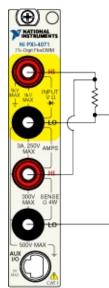


### **2-Wire Resistance**

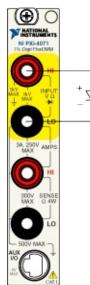
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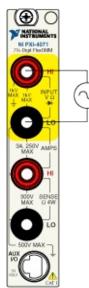
### **4-Wire Resistance**



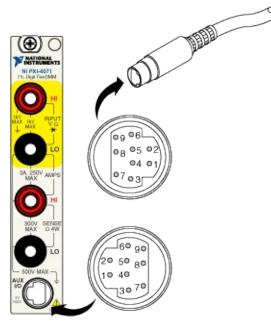
## Voltage Drop Across a Diode



# **Frequency/Period**



# **SCXI** Communication



The following table shows the pins used for SCXI communication:

Pin	Assignment
1–5, 7–9	SCXI Communication

#### **Cable Accessory**

Note When certain NI-PXI 407x devices are installed in the rightmost slot of a PXI/SCXI combination chassis, they can control the SCXI portion of the chassis, and no cable is needed. Refer to <u>PXI</u> <u>Express Compatibility</u> and <u>Scanning Switch Modules</u> for more information.

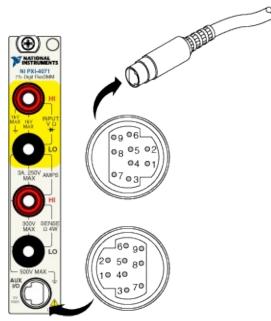
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This SH9MD-AUX cable allows the NI 4070/4071/4072 to communicate with SCXI switches. Refer to <u>Scanning Switch Modules</u> for more information.

For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

# Triggering



The following table shows the pins used for input and output triggers, which are used during synchronous scanning or handshaking:

Pin	Assignment
2	Ground
3	AUX Trigger In
6	Measurement Complete (MC)
9	External Trigger In (Trigger/Sample Trigger)

#### **Cable Accessories**

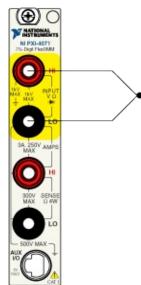
Note When certain NI-PXI 407x devices are installed in the rightmost slot of a PXI/SCXI combination chassis, they can exchange measurement complete (MC) and the input trigger through the backplane, and no cable is needed. Refer to <u>PXI Express</u> <u>Compatibility</u> and <u>Scanning Switch Modules</u> for more information.

AUX Trigger Cable	This cable allows the NI 4070/4071/4072 to trigger
	NI switches, third-party switches, and any other external device during synchronous scanning or handshaking scanning.
	Note The AUX Trigger Cable only provides access to AUX I/O Connector Pins 2, 6, and 9, where Pin 2 is Ground and is present in both ends of the cable.
SH9MD- AUX Cable	This cable allows the NI 4070/4071/4072 to control SCXI switches, send measurement complete (MC), and receive external trigger. This functionality allows the NI 4070/4071/4072 to work under both synchronous scanning and handshaking scanning. Refer to Scanning Switch Modules for more information.

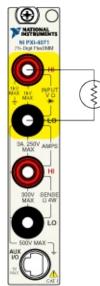
For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

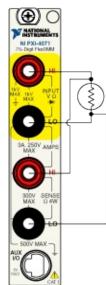
## **Temperature (Thermocouple)**



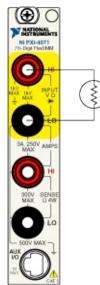
# **Temperature (2-wire RTD)**



# **Temperature (4-wire RTD)**



# **Temperature (Thermistor)**



## **DC and AC Current**

The NI 4071 allows you to measure currents ranging from a few picoamps to three amperes. DC Current mode has eight ranges that go from 1  $\mu$ A to 3 A in decades, and AC Current mode has six ranges that go from 100  $\mu$ A<sub>rms</sub> to 3 A<sub>rms</sub> in decades. The AC Current mode uses the same fast measurement technique as the AC Volts DC Coupled mode.



Note AC current measurements are always DC coupled and therefore always offer low settling time. Keep in mind that the range chosen needs to include both the signal range and its offset, otherwise the input can get overloaded. For a list of the available ranges, refer to <u>Related Documentation</u> for the NI 4071 specifications document.

#### **Shunt Resistors**

The NI 4071 uses internal shunt resistors with temperature coefficient and power ratings selected to reduce <u>resistor self-heating</u> errors. For the effect of temperature changes on the accuracy of the measurements, refer to <u>Related Documentation</u> for the NI 4071 specifications document and the temperature coefficient. Refer to the following table for the shunt resistor values.

Range	Shunt Resistor Value
3 A	0.05 Ω
1 A	0.05 Ω
100 mA	0.5 Ω
10 mA	5 Ω
1 mA	50 Ω
100 µA	500 Ω
10 µA	55 kΩ
1 µA	55 kΩ

**Tip** The current measurement path within the NI 4071 utilizes an electromechanical relay that provides very low resistance to assure a low burden voltage. While this relay has an exceptionally long life, you can take special precautions to ensure reliable operation.

Whenever possible, switch the NI 4071 into the current measurement function before applying the current. Switching inductive current sources generally creates flyback voltages that stress the relay and, if done frequently, can shorten the reliability of the relay. Also, avoid interrupting the current by switching out of the current measurement function when currents are flowing through the circuit.

#### **Input Protection**

The current-measuring circuit is protected with a fuse rated at F 3.15 A 250 V. The NI 4065 and NI 4071 can measure up to 3 A DC or 3  $A_{rms}$  with up to 4.2 A peak current (sine wave only). Higher currents will blow the fuse.

If you apply higher current level to a range, the input protection circuitry of the NI 4065 and NI 4071 automatically engage, and you receive an overrange warning.

Also, keep in mind that exposing the current measurement connectors to voltage sources while the DC or AC current functions are selected may trigger the input protection circuitry or even blow the fuse. Do not apply more than 150 mV to the 1 A and 3 A ranges, or more than 1 V to any of the other ranges.

For more information on fuse replacement, refer to <u>Related</u> <u>Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

## NI 4070

The NI 4070 is a 6½ digit DMM for the PXI and PCI buses. The NI 4070 can acquire waveforms at 1.8 MS/s. For more information about the NI 4070 specifications, refer to <u>Related Documentation</u> for the NI 4070 specifications document.

This topic contains the following subsections:

- Interconnects and Cables
- **Operation**
- <u>Replacing the Fuse</u>
- Calibrating the NI 4070

#### **Interconnects and Cables**

The front of the NI 4070 module has five connectors—four banana plug connectors and one 9-pin mini–circular DIN connector. The four banana plug connectors are high-voltage, safety-agency approved signal connectors. The 9-pin DIN connector labeled AUX I/O is a digital signal connector, which carries triggers and SCXI communication signals. For an illustration of the front panel connectors and wiring instructions, refer to NI 4070 Front Panel Connections.

The input connectors on the NI 4070 are gold-plated, low-thermal copper for best low-voltage performance. The insulator material is a Lexan compound, optimized for low leakage over the full environmental operating range.

For use with the NI 4070, NI recommends selecting a cable with characteristics similar to the Belden 83317E; refer to the Belden CDT Incorporated Web site at <u>www.belden.com</u> for information about this cable.

Tape-wrapped polytetrafluoroethylene (PTFE) insulation guarantees low leakage. Copper conductors with silver plating perform very well for lowvoltage measurements because of their low thermal characteristics. Use a cable with at least 90% shielding effectiveness.

Belden #83317E Teflon Insulated Cable				
Type of Insulator	AWG	Conductor Material	Resistance per Foot	Capacitance per Foot
TFE	26	Silver-plated copper, stranded	39 mΩ	35.5 pF

### Operation

The NI 4070 can operate as a DMM and can <u>acquire waveforms</u> up to 1.8 MS/s. The following table lists the functions and ranges supported by the NI 4070 while in DMM mode:

DMM Function	Ranges	
DC Voltage	100 mV, 1 V, 10 V, 100 V, 300 V	
AC Voltage	50 mV, 500 mV, 5 V, 50 V, 300 V	
DC Current*	20 mA, 200 mA, 1 A	
AC Current*	10 mA, 100 mA, 1 A	
2-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ, 10 MΩ, 100 MΩ	
4-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ, 10 MΩ	
Diode	10 V at 1 μA / 10μA / 100μA; 4.5 V at 1 mA	
Frequency/Period	50 mV, 500 mV, 5 V, 50 V, 300 V	
* To measure current outside of the normal range on the NI 4070, you must use a current shunt		

module (CSM). Refer to <u>Measuring Current</u> for more information.

The following table lists the functions and ranges supported for waveform acquisitions:

Waveform Function	Ranges	Coupling	
Voltage Waveform	100 mV, 1 V, 10 V, 100 V, 300 V	AC or DC	
Current Waveform*	20 mA, 200 mA, 1 A	DC	
* To measure current outside of the normal range on the NI 4070, you must use a current shunt			

module (CSM). Refer to <u>Measuring Current</u> for more information.

#### **Additional Features**

- <u>Self-Calibration</u>
- Auto Zero
- <u>Configuring Auto Range</u>
- Offset Compensated Ohms
- ADC Calibration
- Input Resistance
- <u>Configuring Measurement Timing</u>

- Aperture Time
- DC Noise Rejection
- <u>Waveform Acquisitions</u>
- Single Point Acquisitions
- <u>Generating Measurement Complete</u>
- <u>Scanning Switch Modules</u>

#### **Replacing the Fuse**

The NI 4070 is equipped with a F 1.25 A 250 V Fast–Acting fuse designed to help protect the DMM and your test system. For instructions on replacing the fuse, refer to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

### Calibrating the NI 4070

Calibration maximizes the accuracy of a DMM. To ensure accuracy, you must perform calibration. NI recommends that you externally calibrate every two years. Refer to <u>self-calibration</u> or <u>ADC calibration</u> to internally calibrate the NI 4070. Refer to the *NI 4070/4072 6<sup>1</sup>/<sub>2</sub> Digit FlexDMM Calibration Procedure* at the <u>NI Calibration Solutions</u> Web site for information on externally calibrating the NI PXI/PCI-4070/4072. For information on calibrating the NI 4070 using National Instruments Calibration Executive, refer to the <u>NI Calibration Solutions</u> Web site. All NI measurement devices receive NIST-traceable calibration before shipping.

## **Front Panel Connections**

Move the mouse over the text to view the wiring diagrams for the NI 4070, and click for additional information.

DC Voltage

AC Voltage

DC Current

AC Current

2-Wire Resistance

4-Wire Resistance

Voltage Drop Across a Diode

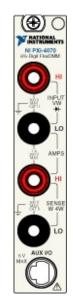
**Frequency/Period** 

Voltage Waveform

**Current Waveform** 

**SCXI** Communication

**Triggering** 



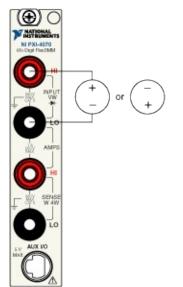
Temperature (Thermocouple)

Temperature (2-wire RTD)

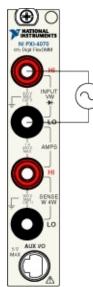
Temperature (4-wire RTD)

Temperature (Thermistor)

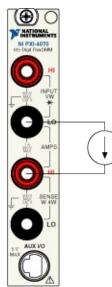
## **DC Voltage**



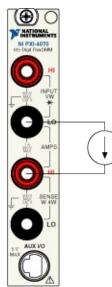
# AC Voltage



### **DC Current**

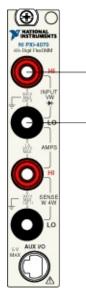


### **AC Current**

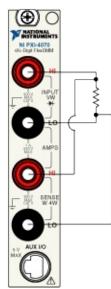


## **2-Wire Resistance**

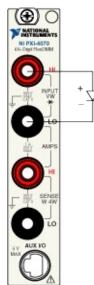
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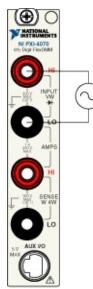
## **4-Wire Resistance**



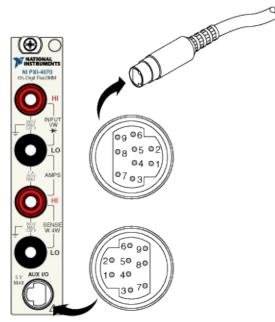
# Voltage Drop Across a Diode



# **Frequency/Period**



# **SCXI** Communication



The following table shows the pins used for SCXI communication:

Pin	Assignment
1–5, 7–9	SCXI Communication

### **Cable Accessory**

Note When certain NI-PXI 407x devices are installed in the rightmost slot of a PXI/SCXI combination chassis, they can control the SCXI portion of the chassis, and no cable is needed. Refer to <u>PXI</u> <u>Express Compatibility</u> and <u>Scanning Switch Modules</u> for more information.

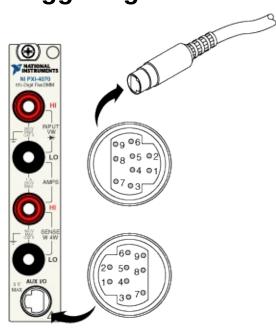
1110		
Jan Start St	- Aller	

This SH9MD-AUX cable allows the NI 4070/4071/4072 to communicate with SCXI switches. Refer to <u>Scanning Switch Modules</u> for more information.

For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

# Triggering



The following table shows the pins used for input and output triggers, which are used during synchronous scanning or handshaking:

Pin	Assignment
2	Ground
3	AUX Trigger In
6	Measurement Complete (MC)
9	External Trigger In (Trigger/Sample Trigger)

### **Cable Accessories**

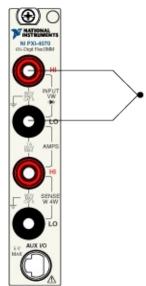
Note When certain NI-PXI 407x devices are installed in the rightmost slot of a PXI/SCXI combination chassis, they can exchange measurement complete (MC) and the input trigger through the backplane, and no cable is needed. Refer to <u>PXI Express</u> <u>Compatibility</u> and <u>Scanning Switch Modules</u> for more information.

AUX Trigger Cable	This cable allows the NI 4070/4071/4072 to trigger
	NI switches, third-party switches, and any other external device during synchronous scanning or handshaking scanning.
	Note The AUX Trigger Cable only provides access to AUX I/O Connector Pins 2, 6, and 9, where Pin 2 is Ground and is present in both ends of the cable.
SH9MD- AUX Cable	This cable allows the NI 4070/4071/4072 to control SCXI switches, send measurement complete (MC), and receive external trigger. This functionality allows the NI 4070/4071/4072 to work under both synchronous scanning and handshaking scanning. Refer to Scanning Switch Modules for more information.

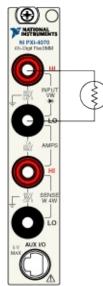
For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

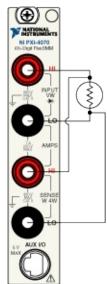
# **Temperature (Thermocouple)**



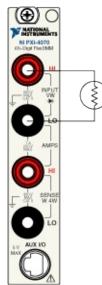
# **Temperature (2-wire RTD)**



# **Temperature (4-wire RTD)**



# **Temperature (Thermistor)**



## NI 4065

The NI 4065 is a 6½ digit DMM for the PXI, PCI, PCI Express, and USB buses. For more detailed information about the NI 4065 specifications, refer to <u>Related Documentation</u> for the *NI 4065 Specifications* document.

### **Front Panel Connections**

The PXI, PCI, and PCI Express front panels have four shrouded banana plug connectors and one 9-pin mini–circular DIN connector. The NI USB-4065 has five shrouded banana plug connectors on the front panel and one 9-pin mini–circular DIN connector on the back panel. The banana plug connectors are high-voltage, safety signal connectors. The 9-pin DIN connector labeled AUX I/O is a digital signal connector, which carries triggers and SCXI communication signals. For an illustration of the front panel connectors and wiring instructions, refer to NI 4065 Front Panel Connections.



**Note** The additional connector on the NI USB-4065 allows you to measure voltage while current is still flowing through the current measurement leads. For more information on the added flexibility of this additional connector, reference KnowledgeBase entry 4GJD4MMP. Refer to ni.com/support to access the KnowledgeBase.

### Operation

The following table lists the functions and ranges supported by the NI 4065:

Function	Ranges
DC Voltage	100 mV, 1 V, 10 V, 100 V, 300 V
AC Voltage	200 mV, 2 V, 20 V, 300 V
DC Current	10 mA, 100 mA, 1 A, 3 A
AC Current	10 mA, 100 mA, 500 mA, 3A
2-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ, 10 MΩ, 100 MΩ
4-Wire Resistance	100 Ω, 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ
Diode	10 V at 100 µA, 3.5 V at 1 mA

#### **Additional Features**

- Auto Zero
- <u>Configuring Auto Range</u>
- <u>Configuring Measurement Timing</u>
- Single Point Acquisitions
- <u>Generating Measurement Complete</u>
- <u>Scanning Switch Modules</u>

### **Replacing the Fuse**

The NI 4065 is equipped with a F 3.15 A 250 V Fast–Acting fuse designed to help protect your module and test system. For instructions on replacing the fuse, refer to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

### **Calibrating the NI 4065**

Calibration maximizes the accuracy of a DMM. To ensure accuracy, you must perform calibration. NI recommends you calibrate annually.

Refer to the *NI 4065 6½ Digit DMM Calibration Procedure* at the <u>NI Calibration Solutions</u> Web site for information on externally calibrating the NI PXI/PCI/PCIe-4065. For information on calibrating the NI 4065 using National Instruments Calibration Executive, refer to the <u>NI Calibration Solutions</u> Web site.

## **Front Panel Connections**

Move the mouse over the text to view the wiring diagrams for the NI 4065, and click for additional information.

DC Voltage

AC Voltage

DC Current

AC Current

2-Wire Resistance

4-Wire Resistance

Voltage Across a Diode

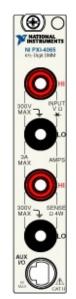
**SCXI** Communication

**Triggering** 

Temperature (Thermocouple)

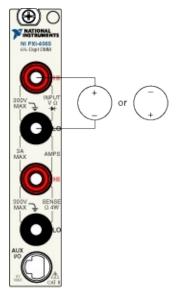
Temperature (2-wire RTD)

Temperature (4-wire RTD)

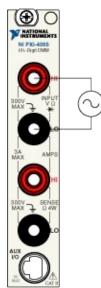


Temperature (Thermistor)

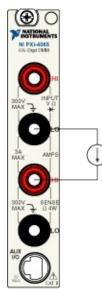
## **DC Voltage**



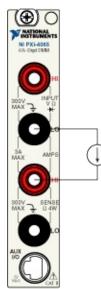
# AC Voltage



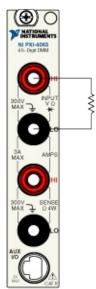
## **DC Current**



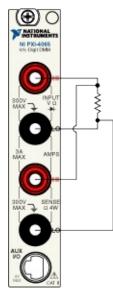
## **AC Current**



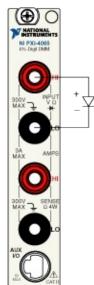
## **2-Wire Resistance**



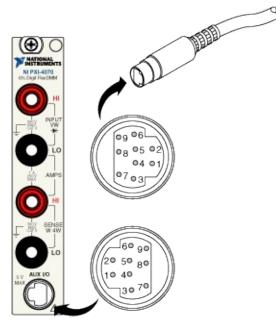
## **4-Wire Resistance**



# Voltage Drop Across a Diode



# **SCXI** Communication



The following table shows the pins used for SCXI communication:

Pin	Assignment
1-5, 7-9	SCXI Communication

Note The NI USB-4065 does not support the ability to control SCXI switches through the AUX cable. Use the NI USB-1357/1358 SCXI PnP Backplane Kit to control SCXI switches with the NI USB-1359 Adapter and send and receive triggers with the NI SCXI-1359 Adapter. Both the NI USB-1359 and NI SCXI-1359 Adapters are included in the NI USB-1357/1358 SCXI Backplane Kit.

### **Cable Accessory**

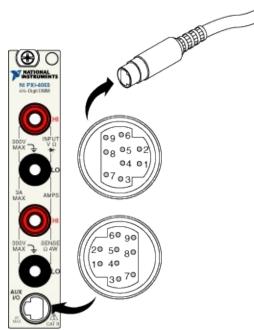
|--|--|--|

This SH9MD-AUX cable allows the NI 4065 to communicate with SCXI switches. Refer to <u>Scanning Switch Modules</u> for more information.

For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»All Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

# Triggering



The following table shows the pins used for input and output triggers, which are used during synchronous scanning or handshaking:

Pin	Assignment
2	Ground
3	AUX Trigger In
6	Measurement Complete (MC)
9	External Trigger In (Trigger/Sample Trigger)
	Note To use the NULLED 4005 with COVI of

Note To use the NI USB-4065 with SCXI switches, use the NI USB-1357/1358 SCXI PnP Backplane Kit to both control SCXI switches through USB, and send and receive triggers through the AUX cable.

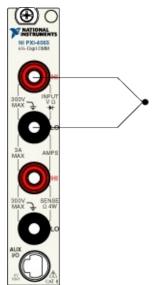
### **Cable Accessories**

AUX Trigger Cable	This cable allows the NI 4065 to trigger NI switches, third-party switches, and any other external device during synchronous scanning or handshaking scanning.
	AUX I/O Connector Pins 2, 6, and 9, where Pin 2 is Ground and is present in both ends of the cable.
SH9MD- AUX Cable	This cable allows the NI PXI/PCI/PCIe 4065 to control SCXI switches, send measurement complete (MC), and receive external trigger. This cable allows the NI USB 4065 to send measurement complete (MC) and receive external trigger. This functionality allows the NI 4065 to work under both synchronous scanning and handshaking scanning. Refer to Scanning Switch Modules for more information.

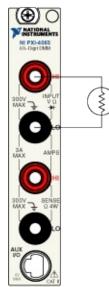
For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

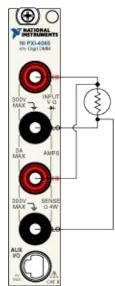
# **Temperature (Thermocouple)**



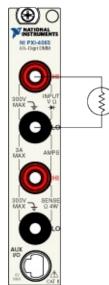
# **Temperature (2-wire RTD)**



# **Temperature (4-wire RTD)**



# **Temperature (Thermistor)**



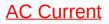
## **NI USB-4065 Front Panel Connections**

Move the mouse over the text to view the wiring diagrams for the NI USB-4065, and click for additional information.

DC Voltage

AC Voltage

DC Current



2-Wire Resistance

4-Wire Resistance

Voltage Across a Diode

**Triggering** 

**Temperature (Thermocouple)** 

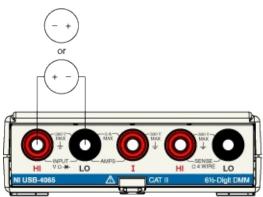
Temperature (2-wire RTD)

Temperature (4-wire RTD)

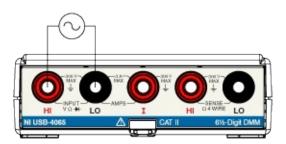
**Temperature (Thermistor)** 



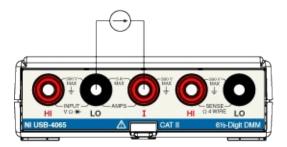
# DC Voltage



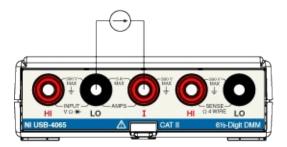
# AC Voltage



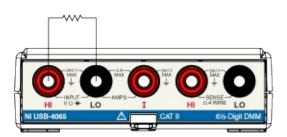
### **DC Current**



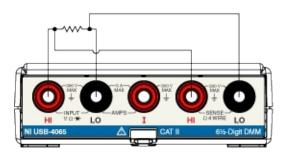
## **AC Current**



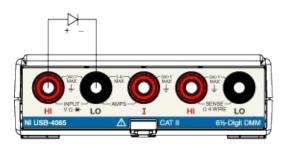
### **2-Wire Resistance**



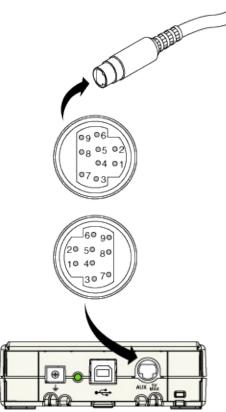
### **4-Wire Resistance**



# **Voltage Drop Across a Diode**



### Triggering



The following table shows the pins used for input and output triggers, which are used during synchronous scanning or handshaking:

Pin	Assignment
2	Ground
3	AUX Trigger In
6	Measurement Complete (MC)
9	External Trigger In (Trigger/Sample Trigger)

Note To use the NI USB-4065 with SCXI switches, use the NI USB-1357/1358 SCXI PnP Backplane Kit to both control SCXI switches through USB, and send and receive triggers through the AUX cable.

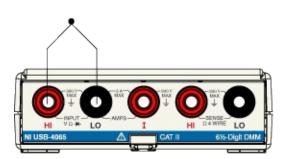
#### **Cable Accessories**

AUX Trigger Cable	This cable allows the NI 4065 to trigger NI switches, third-party switches, and any other external device during synchronous scanning or handshaking scanning.
	AUX I/O Connector Pins 2, 6, and 9, where Pin 2 is Ground and is present in both ends of the cable.
SH9MD- AUX Cable	This cable allows the NI PXI/PCI/PCIe 4065 to control SCXI switches, send measurement complete (MC), and receive external trigger. This cable allows the NI USB 4065 to send measurement complete (MC) and receive external trigger. This functionality allows the NI 4065 to work under both synchronous scanning and handshaking scanning. Refer to Scanning Switch Modules for more information.

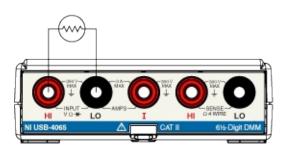
For installation instructions for National Instruments switch modules, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

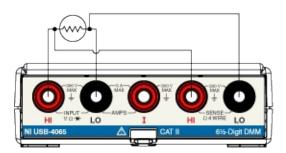
# **Temperature (Thermocouple)**



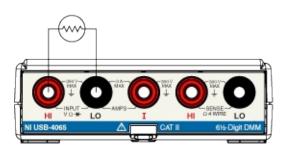
# **Temperature (2-wire RTD)**



# **Temperature (4-wire RTD)**



# **Temperature (Thermistor)**



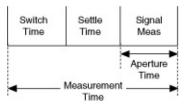
### **DMM Measurements**

The following sections cover optimizing your measurements on the NI 4065.

- DMM Measurement Cycle
- DMM Measurement Defaults
- <u>DC Voltage</u>
- <u>AC Voltage</u>
- DC and AC Current
- <u>Resistance</u>
- <u>Diode</u>

# NI 4065 DMM Measurement Cycle

The NI 4065 measurement cycle is made up of three measurement phases: switch time, settling time, and aperture time. Refer to the figure below for relative timing of these phases. The aperture time is the length of time the signal of interest is being measured. Generally the settle and aperture times are selected by the device driver based on the specified resolution. These values can also be independently controlled. Refer to <u>Configuring Measurement Timing</u> for more information.



The internal switch time is required to configure the analog circuitry of the NI 4065 for the next measurement. This time is not user programmable.

During resistance measurements, the signal is measured with an applied current source. The AC measurement cycle contains the same phases, but the minimum signal measurement time is based on the minimum frequency required of the measurement. For example, for a minimum frequency of 50 Hz with a  $5\frac{1}{2}$  digit resolution, an aperture time of 10x the period of the 50 Hz signal is required, or in this example, 200 ms.

When Auto Range is selected, the Auto Range measurement phase occurs before the signal measurement phases. After the correct range is identified, signal measurements use the selected range.



**Note** When using Auto Range, keep in mind that longer apertures significantly slow down Auto Ranging because multiple measurements are made to find the best range possible. For best measurement speed, manually select the desired range.

# **DMM Measurement Defaults**

The following table lists the default measurement settings for the NI 4065.

Function	Aperture	DC Noise Rejection
DC 6½ digits	200 ms	Second-Order
DC 5½ digits	3.33 ms	Normal
DC 4½ digits	333 μs	Normal
DC Auto Range	3.33 ms	Normal
AC	<ul> <li>AC 6<sup>1</sup>/<sub>2</sub> digits — 1 sec</li> <li>AC 5<sup>1</sup>/<sub>2</sub> digits — Max (100 msec or (10/(minFreq)))</li> <li>AC 4<sup>1</sup>/<sub>2</sub> digits — Max (10 msec or (5/(minFreq)))</li> </ul>	Second-Order
AC Auto Range	Max (100 ms or 10/(minFreq))	Second-Order

By default, the Aperture time and DC Noise Rejection settings for a measurement are chosen by the driver based on the configured measurement and resolution. These values are chosen to ensure accuracy for 6½–digit measurements while not sacrificing performance at lower resolutions. For more information on a particular attribute, including how to configure a non-default setting, refer to Features. For AC, 5.5 digits, the aperture is expressed as Max (AC or 10/minFreq). minFreq, or minimum frequency, is a user–programmable parameter with a default value of 20 Hz.

The same applies for other user selectable values of minFreq. For example, for a minimum frequency of 50 Hz with a  $5\frac{1}{2}$  digit resolution, an aperture time of 10x the period of the 50 Hz signal is required, or in this example, 200 ms.

To adjust the default aperture time, refer to <u>Configuring Measurement</u> <u>Timing</u>.

#### **Default Settling Times**

Function	Settling Time
DC (100 mV-10 V, 100 V, 300 V)	10 ms
Resistance ≤1 kΩ	10 ms
Resistance 10 kΩ	40 ms
Resistance 100 kΩ	200 ms
Resistance 1 M $\Omega$	200 ms
Resistance $\geq$ 10 M $\Omega$	750 ms
AC V AC coupled	1.5 secs
DC I	10 ms
AC I	1.5 secs
Diode	40 ms

To adjust the default settling times, refer to <u>Configuring Measurement</u> <u>Timing</u>.

## **DC and AC Current**

The NI 4065 allows you to measure currents ranging from a few picoamps to three amperes. DC Current mode has four ranges that go from 10 mA to 3 A in decades, and AC Current mode has four ranges that go from 10 mA<sub>rms</sub> to 3 A<sub>rms</sub> in decades.

#### **Shunt Resistors**

The NI 4065 uses internal shunt resistors with temperature coefficient and power ratings selected to reduce <u>resistor self-heating</u> errors. For the effect of temperature changes on the accuracy of the measurements, refer to <u>Related Documentation</u> for the NI 4065 specifications document and the temperature coefficient. Refer to the following table for the shunt resistor values.

Range	Shunt Resistor Value
3 A	0.01 Ω
1 A	0.01 Ω
100 mA	4.8 Ω
10 mA	4.8 Ω

**Tip** The current measurement path within the NI 4065 utilizes an electromechanical relay that provides very low resistance to assure a low burden voltage. While this relay has an exceptionally long life, you can take special precautions to ensure reliable operation.

Whenever possible, switch the NI 4065 into the current measurement function before applying the current. Switching inductive current sources generally creates flyback voltages that stress the relay and, if done frequently, can shorten the reliability of the relay. Also, avoid interrupting the current by switching out of the current measurement function when currents are flowing through the circuit.

### NI 4060

The NI 4060 is a 5½ digit DMM for the PXI and PCI buses. For more detailed information about the NI 4060 specifications, refer to <u>Related</u> <u>Documentation</u> for the NI 4060 specifications document.

#### **Front Panel Connections**

The front of the NI 4060 module has five connectors—four banana plug connectors and one 9-pin mini–circular DIN connector. The four banana plug connectors are high-voltage, safety signal connectors. The 9-pin DIN connector labeled AUX I/O is a digital signal connector, which carries triggers and SCXI communication signals. For an illustration of the front panel connectors and wiring instructions, refer to NI 4060 Front Panel Connections.

#### Operation

The following table lists the functions and ranges supported by the NI 4060:

Function	Ranges	
DC Voltage	20 mV, 200 mV, 2 V, 25 V, 250 V	
AC Voltage	20 mV, 200 mV, 2 V, 25 V, 250 V	
DC Current*	20 mA, 200 mA	
AC Current*	20 mA, 200 mA	
2-Wire Resistance	200 Ω, 2 kΩ, 20 kΩ, 200 kΩ, 2 MΩ, 20 MΩ, 200 MΩ	
4-Wire Resistance	200 Ω, 2 kΩ, 20 kΩ, 200 kΩ, 2 MΩ, 20 MΩ	
Diode	2 V at 100 μA	
* To measure current outside of the normal range on the NI 4060, you must use a current shunt		

module (CSM). Refer to <u>Measuring Current</u> for more information.

#### **Additional Features**

- <u>Auto Zero</u>
- Configuring Auto Range
- <u>Configuring Measurement Timing</u>
- Single Point Acquisitions
- <u>Generating Measurement Complete</u>
- <u>Scanning Switch Modules</u>

#### **Replacing the Fuse**

The NI 4060 is equipped with a F 500 mA 250 V Fast–Acting fuse designed to help protect your module and test system. For instructions on replacing the fuse, refer to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

#### Calibrating the NI 4060

Calibration maximizes the accuracy of a DMM. To ensure accuracy, you must perform calibration. NI recommends you calibrate annually.

For information on calibrating the NI 4060 using National Instruments Calibration Executive, refer to the <u>NI Calibration Solutions</u> Web site.

## **Front Panel Connections**

Move the mouse over the text to view the wiring diagrams for the NI 4060, and click for additional information.

DC Voltage

AC Voltage

DC Current

AC Current

2-Wire Resistance

4-Wire Resistance

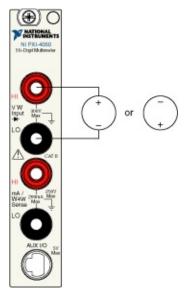
Voltage Across a Diode

**SCXI** Communication

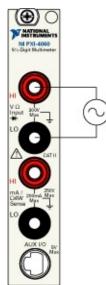
**Triggering** 



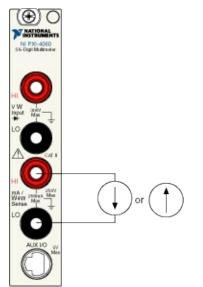
## **DC Voltage**



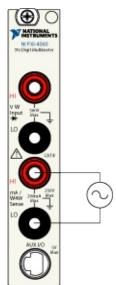
## AC Voltage



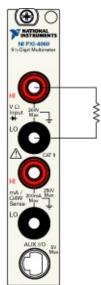
### **DC Current**



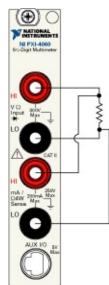
### **AC Current**



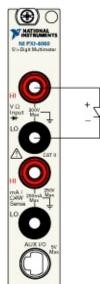
### **2-Wire Resistance**



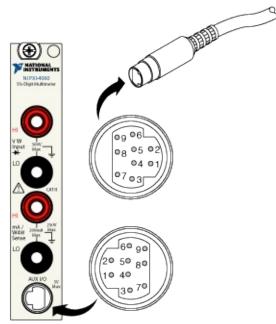
### **4-Wire Resistance**



# Voltage Drop Across a Diode



# **SCXI** Communication



The following table shows the pins used for SCXI communication:

Pin	Assignment
1–5, 7–9	SCXI Communication

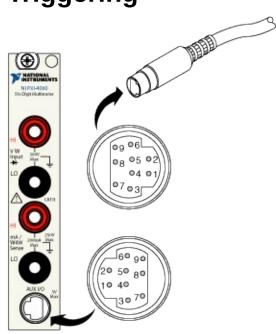
## **Cable Accessory**

Note When the NI PXI-4060 is installed in the right-most slot of a PXI/SCXI combination chassis, the NI PXI-4060 can control the SCXI portion of the chassis through the backplane, and no cable is needed.

	$\square$

This SH9MD-AUX cable allows the NI 4060 to communicate with SCXI switches. Refer to <u>Scanning Switch Modules</u> for more information.

# Triggering



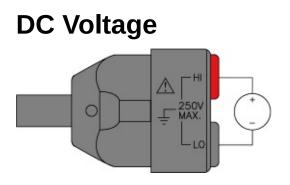
The following table shows the pins used for input and output triggers, which are used during synchronous scanning or handshaking:

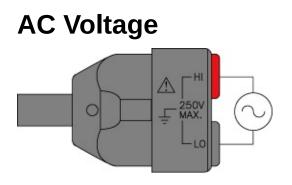
Pin	Assignment
2	Ground
6	Measurement Complete (MC)
9	External Trigger In (Trigger/Sample Trigger)

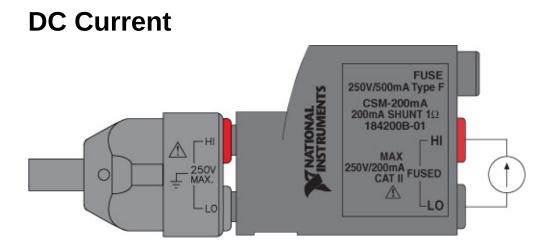
## **Cable Accessories**

Note When the NI PXI-4060 is installed in the right-most slot of a PXI/SCXI combination chassis, the NI PXI-4060 can send MC through the backplane, but requires external cabling to receive the external trigger input. Refer to <u>Scanning Switch Modules</u> for more information.

AUX Trigger Cable	This cable allows the NI 4060 to trigger NI and third-party switches during synchronous scanning or handshaking
	<ul> <li>Scanning.</li> <li>Note The AUX Trigger Cable only provides access to AUX I/O Connector Pins 2, 6, and 9, where Pin 2 is Ground and is present in both ends of the cable.</li> </ul>
SH9MD- AUX Cable	This cable allows the NI 4060 to communicate with SCXI switches and send measurement complete (MC). This functionality allows the NI 4060 to work under synchronous scanning. Refer to Scanning Switch Modules for more information.

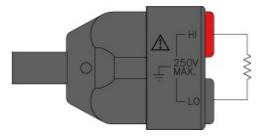




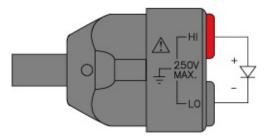


# AC Current

# **2-Wire Resistance**



# Voltage Drop Across a Diode



# Integration and System Considerations

This section includes information related to integrating your DMM with other devices and environments.

# Environment

NI DMMs use precision components whose performance can be adversely affected by operation outside the specified limits. For more information, refer to the *Environment* section in the specifications document of your device at <u>Related Documentation</u>.

For best performance:

- Ensure that the ambient temperature is between 0 °C and 55 °C (NI PXI-4060/4065 and NI PXI-4070/4071/4072), 0 °C and 45 °C (NI USB-4065), or 0 °C and 40 °C (NI PCI/PCIe-4065 and NI PCI-4070).
- Follow standard metrology practices as you would for any ppmlevel measurements.
- Use a chassis that has a well-designed cooling system, allowing the DMM to stay cool. All NI PXI chassis meet this requirement.

Operating the NI 4070/4071/4072 outside the specified operating temperatures can increase bias currents in the electronic components, increase noise, accelerate drifts, and decrease product life. Beyond the maximum specified operating temperatures, the DMM's circuits perform differently than during the factory calibration, resulting in additional measurement errors which may not be accounted for by the Tempco specifications.



Note To ensure PXI, PCI, and PCI Express DMMs operate at peak performance, refer to <u>Chassis</u> for recommendations. To ensure USB DMMs operate at peak performance, refer to <u>USB</u> <u>System Considerations</u> for recommendations.

Operating under high humidity (>80%, >35 °C) or dusty conditions can cause leakages between circuit components to increase and result in additional measurement errors, especially in resistance measurements above 100 k $\Omega$ .

NI used a highly accelerated life test (HALT) to verify the operation of the NI 4070/4071/4072 during severe environmental and operational stresses beyond normal shipping, storage, and operational levels.

You can operate the NI 4070/4071/4072 at temperatures below 0 °C (down to -10 °C) for short periods of time. The NI PXI-4070/4071/4072

operates at about 10 °C higher than the incoming air in the PXI module. Operation above 55 °C could induce gain errors due to the precision reference temperature control dropping out of equilibrium. You can measure the temperature of the DMM using the onboard temperature sensor.

NI designed the NI 4070/4071/4072 with robust built-in precision voltage and resistance standards. These standards and the <u>self-calibration</u> function improve the performance of the NI 4070/4071/4072 at the extremes, even beyond the capability of most other DMMs. Regardless, you should always ensure appropriate environmental requirements are met.

# Chassis

This section specifies the recommended chassis components and conditions for a system that includes National Instruments DMMs.

## **PXI Chassis Recommendations**

The NI PXI-4070/4071/4072 and NI PXI-4060/4065 are designed to operate in any PXI-compliant chassis. Normal operating conditions for these DMMs include the following:

- All PXI filler panels must be installed in empty slots.
- The PXI chassis fans that provide forced air must remain unobstructed to allow for proper cooling of the PXI chassis, devices, and controller.
- Routine maintenance of the chassis cooling fan filters must be performed to assure continuous cooling effectiveness.
- Temperature rise on a module within a chassis can vary with slot position. You can keep this variation to a minimum by taking the precautions listed above.

#### **PXI Express Chassis**

Some PXI Express chassis provide hybrid slots. A hybrid slot can accept either PXI Express modules or PXI Express compatible modules, but not standard PXI modules. To determine if your chassis contains hybrid slots, refer to your chassis documentation. For more information about hybrid slots, refer to the related Web topic <u>PXI Express FAQ</u>.

Refer to <u>PXI Express Compatibility</u>, to determine if your DMM is PXI or PXI Express compatible and for more information about PXI Express compatibility.

## **PCI Chassis Recommendations**

The NI PCI-4070, NI PCI/PCIe-4065, and NI PCI-4060 are designed to operate in any ATX-compliant industrial or personal computer. Normal operating conditions for these DMMs include the following:

- All covers for the industrial chassis or personal computer must be installed.
- All PCI filler panels must be installed to close off unused PCI slots.
  - **Caution** For optimal electromagnetic compatibility (EMC) performance and input protection, you *must* install the front panel screw.
- The PCI front panel bracket on the NI PCI/PCIe-4065, NI PCI-4060, and NI PCI-4070 must have a firm, direct, metal-to-metal mounting connection to ensure proper grounding. Some computer manufacturers use a securing lever made of plastic; such a lever is unacceptable for safety reasons and must be removed. The PCI devices must be screwed down. If the chassis does not meet these requirements, you must use a different computer chassis.

The cooling capability in most industrial and personal computers is less effective than the cooling capability in a PXI chassis. The NI PCI/PCIe-4065 and NI PCI-4060 dissipate low enough power that additional cooling is not needed in most computers. The NI PCI-4070 dissipates higher power, and NI strongly recommends that NI PCI-4070 users implement the following precautions to maximize the cooling capability of the computer:

- Install an additional 80 mm, 32 cubic ft/min (CFM) fan that forces air towards the NI PCI-4070 or NI PCI-4060. Most computer chassis contain one or two mounting locations for this type of fan. These fans are inexpensive and readily available at most computer supply stores.
  - Note If the hard drive mounts vertically in front of the fan mounting location(s) in the computer chassis, you must move the hard drive to a horizontal 3.5 inch drive bay or to another suitable location that does not obstruct the fan mounting location(s).

• Add additional fans, such as PCI fan cards and chassis fans, to increase the air circulation inside the computer.

## **USB System Considerations**

The NI USB-4065 conforms to USB 2.0 specifications and is 1.1 compliant. The NI USB-4065 is a high powered USB device that supports both Hi-Speed and full-speed USB protocol. For more information about power requirements, refer to <u>Related Documentation</u> for the *NI 4065 Specifications* document.

# **Using Switches**

Refer to <u>Triggering</u> for more information.

In applications where you are connecting many test points to the DMM, it may be appropriate to incorporate a switch. Switches are used to route signals between test points and instruments.

Switch selection should be based on the signal types you are routing and the topology required.

For current and resistance measurements, the switch should have very low path resistance (for example, under 1–2  $\Omega$  path resistance). Refer to <u>Offset Compensated Ohms</u> for optimizing resistance measurements in the presence of relay thermal offsets. For capacitance and inductance measurements, it is necessary to have 1–2  $\Omega$  path resistance as well. Electromechanical switches are a good match for these applications.

For high–speed scanning through different channels, solid–state relays (SSRs) or FET switches work well. They have high path resistances, so they work best for high-impedance voltage measurements. FET switches operate at logic levels and are usually very fast (25 to 100 kHz), at the expense of low maximum voltage limits (<10 V). SSRs provide internal isolation that allow them to switch much higher voltages (300 V), but they are not as fast as their FET counterparts (1 to 2 kHz).

For low-voltage measurements, keep in mind that the relay section determines the ultimate measurement error due to contact thermal voltages. Refer to <u>Optimizing Low-Voltage Measurements</u> for more information.

Function	Electromechanical	SSR	FET
Voltage	Up to 300 V	Up to 300 V	Up to 10 V
Current	Up to 10 A	Up to 300 mA	<10 mA
Resistance	Recommended	For 4-wire measurements, check the maximum lead resistance allowed by the DMM <sup>1</sup>	For 4-wire measurements, check the maximum lead resistance allowed by the DMM <sup>1</sup>
Capacitance	Recommended	Not recommended	Not recommended

and Inductance			
Scanning Speed	Up to 100 channels/second	Up to 2,000 channels/second	Up to 100,000 channels/second
Lifetime	10 <sup>7</sup> operations	No theoretical limit	No theoretical limit
<sup>1</sup> Not recommended for 2-wire measurements below 10 k $\Omega$ . Switch resistance must be nulled prior to resistance measurement. Refer to Offset Nulling.			

# **Switch Fundamentals**

Refer to the following topics for fundamental information about switches:

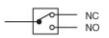
- <u>Relay forms</u>
- <u>Topologies</u>
- <u>Settling times and switches</u>

#### **Relay Forms**

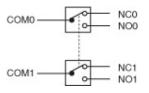
Relays are classified by their number of poles and number of throws. The pole of a relay is the terminal common to every path. Each position that the pole can connect to is called a throw. A relay can be made of *n* poles and *m* throws. For example, a single-pole single-throw relay (SPST) has one pole and one throw, as illustrated in the following figure.



A single-pole double-throw (SPDT) relay has one pole and two throws, as illustrated in the following figure.



A double-pole double-throw (DPDT) relay has two poles, each with two simultaneously controlled throws, as illustrated in the following figure.



Relays are then classified into forms. Relay forms are categorized by the number of poles and throws as well as the default position of the relay. Three common relay forms are: A, B, and C.

#### Form A

Form A relays are SPST with a default state of normally open.

## ••

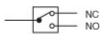
#### Form B

Form B relays are SPST with a default state of normally closed.



#### Form C

Form C relays are SPDT and break the connection with one throw before making contact with the other (break-before-make).



### Topologies

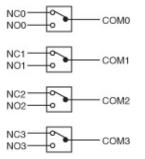
A switch topology is an organizational representation of the channels and relays in a switch module. The topology establishes the default states for all relays in a module and defines the channel names. Some switches can use multiple topologies or variations of each topology type. Some terminal blocks or accessories may force the switch to use a given topology or set of topologies.

NI switches use three categories of topologies:

- <u>General-purpose</u>
- <u>Multiplexer</u>
- <u>Matrix</u>

#### **General-Purpose Topologies**

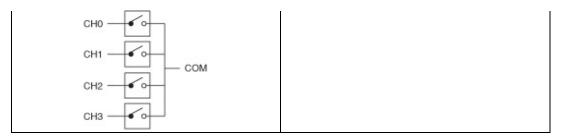
General-purpose topologies consist of multiple isolated relays. Each channel of a general-purpose switch module can connect one input to one output. They are typically used to power ON or OFF devices such as motors, fans, and lights or to switch high-voltage or high-current signals.



#### Multiplexer

A multiplexer, or a MUX, is a topology in which you can connect one input to multiple outputs or one output to multiple inputs. This topology is often used for scanning when you need to automatically connect a sequence of channels to a common line.

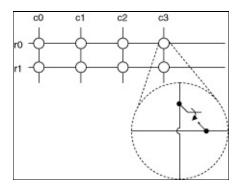
4x1 Multiplexer	4x1 Multiplexer
Composed of Form A Relays	Composed of Form C Relays
	CH2 CH2 CH3



#### Matrix

A matrix is one of the most flexible switching configurations. Unlike a multiplexer, a matrix can connect multiple inputs to multiple outputs organized as columns and rows. You can connect any column to any number of rows and any row to any number of columns. At each intersection of a row and column, there is a switch. When the switch is closed, the row is connected to the column.

Matrix size is often described as M rows by N columns (M x N). The figure below depicts a 1-wire, 2 x 4 matrix, where  $c_n$  is any device under test (DUT) and  $r_n$  is any of the instruments, including the DMM.



#### **Settling Time and Switches**

When using switches in an application, you need to consider switching and measurement timing issues. Switches take time to actuate and settle, so changing channels requires care to avoid compromising the measurement with a DMM.

Electromechanical switches use coil-induced magnetic fields to move an armature and connect two contacts, completing the circuit. The time it requires is called relay actuation time. The actuation time required to close a contact usually takes longer than the time it takes to break the connection.

FET switches use transistor devices to modulate path resistance. The actuation time is based on charging the gate of these transistors and semiconductor device physics, and it is much faster than actuating the armature of an electromechanical switch.

Solid–state relays (SSR) also use transistors to create the circuit. To provide high-voltage switching capability, the gate is driven by an optical isolator. The optical isolator takes longer to charge and actuate the switch than the non-isolated gate of a FET switch, but it is faster than an electromechanical switch.

In addition to actuation time, switches require a settling time. After an electromechanical switch actuates, the armature vibrates, or bounces, on the channel contact. Measurements cannot be made until this effect has subsided. Settling time can also be affected by the length and type of external cabling. The DMM should wait for the switch to actuate and for the system to settle before taking a measurement. The total settling time is dependent on the required accuracy. For information on settling time, refer to <u>Settling Time</u>.

If you are using National Instruments switches, you can exchange triggering signals between the switches and the DMM (handshaking), or the DMM can signal the switch to actuate (synchronous scanning). Refer to <u>Scanning Switch Modules</u> for information about how National Instruments DMMs and switch modules can exchange trigger signals.

# Load Switching

This topic addresses analog signal-path related challenges associated with connecting a DUT, a switch, and a high-performance DMM. Topics include the following:

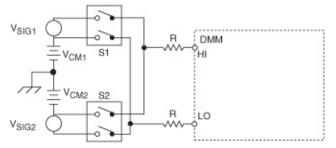
- <u>Switching voltages</u>
- Switching current
- Switching capacitance and inductance

## **Switching Voltages**

When switching high-voltage signals, the parasitic capacitance of the cable connecting the NI 4065 and NI 4070/4071/4072 with the switches, as well as the input capacitance of the instrument, need to be charged to the source voltage. Depending on the voltage present at the DMM input during the measurement on the previous channel, a significant current can flow from the high–voltage source to charge this capacitance. This action is referred to as hot switching, which can reduce the life of the switches. Refer to your switch documentation for information about extending switch life.

When switching high-voltage signals into a low-voltage range of any DMM (such as applying 300 V on the 10 V range), the input impedance will be lower than it is when the proper range is selected. Repetitive operations like this may shorten switch life. To maximize switch life, always select a measurement range that can handle the maximum voltage expected.

Switching signals with large common-mode components (LO switched from +250 V to -250 V) may, over extended periods of time (tens of Hz for several weeks) begin to degrade the relay performance. The switching life of the relays can be extended in many cases by inserting some small common-mode resistance in series with the LO terminals. Even several hundred ohms (200 to 500  $\Omega$ ) helps significantly. Refer to the following figure, where  $V_{CM1}$  or  $V_{CM2} > 50$  V:



In these situations, break-before-make switching is essential to obtaining any kind of reliable relay life. Should  $S_1$  and  $S_2$  be turned on together, even momentarily,  $V_{CM1} + V_{SIG1}$ , is shorted to  $V_{CM2} + V_{SIG2}$ , which could cause high currents to permanently damage the contacts of  $S_1$  or  $S_2$ .

#### Low Voltages

When setting up systems using relay switching, keep in mind that low–voltage performance is largely limited by the switches selected and the input terminals used on the switch.

Good low-thermal relay switching cards are available from NI.

Common, uncompensated reed relays can reach tens of  $\mu$ V of rather unstable offset, but high–performance reeds can reach below 1  $\mu$ V.

Many armature–style latching reed relays can give very low drift (one such device is used in the NI 4065 and NI 4070/4071/4072 signal path). It is sometimes possible to compensate for this drift by using similar relays in both HI and LO connections or by placing adjacent poles of a 2–pole relay back–to–back.

Lastly, a common metrology technique involves making a measurement, reversing the leads, taking another measurement, and subtracting and averaging the two readings.

#### **High Voltages**



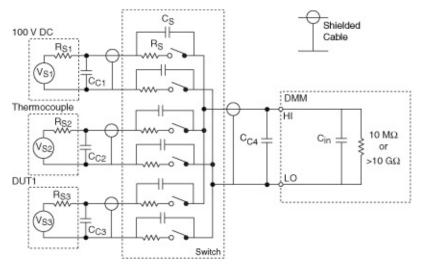
**Caution** All cables, connectors, and fixtures used in your system must have specifications to handle with an adequate safety margin 1000 V signals for the NI 4071 and 300 V signals for the NI 4065 and NI 4070/4072.

When switching high-voltage signals, the parasitic capacitance of the cable connecting the NI 4065 and NI 4070/4071/4072 with the switches, as well as the input capacitance of the instrument, needs to be charged to the source voltage. Depending on the voltage present at the DMM input during the measurement on the previous channel, a significant current can flow from the high-voltage source to charge this capacitance.

This current transient does not cause any degradation effect on the NI 4065 and NI 4070/4071/4072, but this action, referred to as hot switching, can reduce the life of the switches. Refer to Handling High DC Voltages for more information about the degradation effect, and refer to the switch documentation for information about extending switch life.

When switching high-voltage signals into a low-voltage range of any DMM (such as applying 300 V on the 10 V range), the input impedance is lower than it is when the proper range is selected. Repetitive operations such as these may shorten switch life. To maximize switch life, always select a measurement range that can handle the maximum voltage expected.

Remember that you might need to increase the settling time of your measurement. Consider the following illustration showing a DMM connected to a 100 V DC source, a thermocouple, and device under test (DUT) through a multiplexing switch.



For example, assume you are switching from the 100 V range to the 100 mV range and want to obtain the best sensitivity using the thermocouple. When the switch module advances from the 100 V channel to a thermocouple channel, the input signal conditioning of the DMM (along with the cabling, switching module, and so on) must discharge any stray capacitance from 100 V to 100  $\mu$ V. If you need a sensitivity of 1  $\mu$ V from the low–voltage channel, the system must settle from 100 V to 1  $\mu$ V (10 parts per billion, or eight decades).

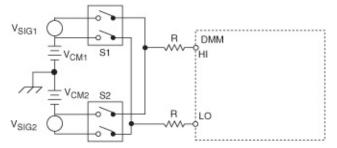
When you require resolutions better than 10 ppm, <u>dielectric absorption</u> is a major factor.

Depending upon the source resistance (R), system capacitance (C), and dielectric qualities of the system components, you must allow more settling time in this example. In practice, you may need to allow settling times of 10 ms or more in situations where you are switching high voltages (>30 V).

## **Voltages with Large Common-Mode Components**

Switching signals with large common-mode components (LO switched from +250 V to -250 V) may, over extended periods of time (tens of Hz for several weeks), begin to degrade the relay performance. The switching life of the relays can be extended in many cases by inserting some small common-mode resistance in series with the LO terminals. Even several hundred ohms (200 to 500  $\Omega$ ) helps significantly.

Refer to the following figure, where  $V_{CM1}$  or  $V_{CM2}$  are >50 V:



P

In these situations, break-before-make switching is essential to obtaining any kind of reliable relay life. If *S1* and *S2* are turned on together, even momentarily, *VCM1* + *VSIG1*, is shorted to *VCM2* + *VSIG2*, which could cause high currents to permanently damage the contacts of *S1* or *S2*. The transient signal generated when switching signals with large common mode voltages closely resemble the effect of applying signals that exceed the V-Hz limit. This could affect the internal transfer of data in the device and would generate an error prompting you to reset the board and reconfigure your measurement. Refer to Handling High DC Voltages for more information.

**Tip** If the NI 4070/4071/4072 experiences the conditions where the transients cause the violation of the V-Hz limit of the instrument while the instrument is making measurements, NI-DMM driver returns error NIDMM\_ERROR\_SERIAL\_PORT\_ERROR (defined as 0xBFFA401F, or -1074118625). If your system can potentially face this situation, your application should look for this error code after a call to:

- niDMM Read (niDMM\_Read)
- niDMM Read Multipoint (niDMM\_ReadMultipoint)
- niDMM Fetch (niDMM\_Fetch)
- niDMM Fetch Multipoint (niDMM\_FetchMultipoint)

Your application can handle this error by calling the following VIs or functions:

- 1. <u>niDMM Reset (niDMM\_reset</u>)
- 2. Any configuration VI or function to reconfigure the instrument to the required settings
- 3. <u>niDMM Initiate</u> (<u>niDMM\_Initiate</u>), <u>niDMM Read</u> (<u>niDMM\_Read</u>), or <u>niDMM Read Multipoint</u> (<u>niDMM\_ReadMultipoint</u>) to restart the measurement

## **Switching Current**

The current measurement path within the NI 4065 and NI 4070/4071/4072 utilizes an electromechanical relay that provides very low resistance to assure a low burden voltage. While this relay has an exceptionally long life, you can take special precautions to ensure reliable operation.

Whenever possible, switch the NI 4065 and NI 4070/4071/4072 into the current measurement function before applying the current. Switching inductive current sources generally creates flyback voltages that stress the relay and, if done on a frequent basis, can shorten the reliability of the relay. Also, avoid interrupting the current by switching out of the current measurement function or resetting the DMM when currents are flowing through the circuit.

While the internal shunts are ideal for many applications, in applications where more than one current needs to be measured using the same DMM and the conditions require that the current cannot be interrupted across the load, you can use a break-before-make switch in multiplexer topology and place external shunts across the channels. Connect the shunts in series with the circuit under test and then measure the voltage drop across the shunts.

If the conditions allow interrupting the current flow through the circuit under test, it is still recommended to use external shunts. It is not common to find switches that can switch currents higher than 1 A, and switching currents can diminish the life of the switch.

The benefits of using the break-before-make switch in multiplexer topology with external shunts across the channels are as follows:

- Allows uninterrupted switching of current sources because the multiplexer switches voltages developed across the shunts instead of routing currents; ensuring that the current loop is not interrupted is generally helpful to avoid disturbing the current sources
- Extends the switch life, especially if the switch consists of electromechanical relays

The tradeoffs involved may be as follows:

• Reduces accuracy, although using the DMM to measure the

resistance of shunts periodically (in 4-wire) can address this issue

- Introduces a leakage current from the switch that could significantly affect low-level current measurements; refer to your switch documentation for methods to reduce leakage currents
- Introduces errors due to <u>resistor self-heating</u> in high-level current measurements if the shunt resistor characteristics are not good enough

You should choose a shunt resistor whose characteristics and value help you reduce noise and errors, as follows:

- Consider the tradeoff between creating a large enough voltage across the shunt for resolution, while at the same time keeping the shunt voltage small enough to prevent high heat dissipation or <u>burden voltage</u> errors during the measurement.
- Look for a shunt resistor with low temperature coefficient (preferably not more than 10 ppm/°C) and absolute tolerance matched to your application requirement.

Recall that voltage offsets introduced by the switch could affect your measurement, because they add an additional burden voltage to the one specified by the ammeter itself. For the burden voltage per range, refer to <u>Related Documentation</u> for the specifications documents for the DMMs.

In cases where you must use the built-in current measurement capability of the NI 4065 and NI 4070/4071/4072, use a make-before-break setup for the switches for ensuring uninterrupted current loops. You may also choose to use specially designed current routing switches for this application.

Refer to *DC* and *AC Current* for the <u>NI 4070/4072</u> or the <u>NI 4065</u> and <u>NI 4071</u> for general information about current measurements with the NI 4065 and NI 4070/4071/4072 and for recommendations when taking low and high level current measurements.

## Switching Capacitance and Inductance

The NI 4072 can be integrated as part of an ATE system that includes switches, cables, and other custom test fixtures. The quality of the measurement is directly related to the quality of the system setup.

For information about the various National Instruments switch modules that are available, refer to the *NI Switches Help* at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>ni.com/manuals</u> (if you have *not* installed NI-SWITCH)

#### **Measurement Considerations**

Inductors and capacitors store energy. Inductors store currents that can damage other devices connected to them when disconnected. Capacitors store energy as voltage that can be harmful to some equipment or to the capacitors themselves.

For applications that require scanning through different types of measurements, NI recommends taking notice when switching channels that use built-in current excitation. The measurement modes in the NI 4072 that use current excitation are as follow:

Type of Excitation Signal	Function Mode
DC Current	Resistance
	Refer to the <u>Resistance</u> section for more information on the test current.
	Diode
	Refer to the <u>Diode</u> section for more information on the test current.
AC Current	Capacitance
Current	Refer to the Capacitance and Inductance Measurement

Considerations section for more information on the test signal for capacitance measurements.
Inductance
Refer to the <u>Capacitance and Inductance Measurement</u> <u>Considerations</u> section for more information on the test signal for inductance measurements.

After a measurement is completed, the front-end configuration remains unchanged until the next type of measurement is initiated or the DMM is reset. Therefore, after taking a resistance, diode, capacitance, or inductance measurement, the current excitation remains on until <u>niDMM</u> <u>Initiate</u> (after configuring the device) or <u>niDMM Reset</u> is called. The existing excitation current could lead to an unsafe condition for the setup, the device under test, or the operator.

To avoid such situations, review the channel assignments and configuration of your system, taking into account the following considerations:

- After taking a resistance measurement, turn off the DC current before switching to a channel for a capacitance or inductance measurement. If the resistance or diode DC current excitation is applied to a capacitor, the voltage can increase to 12 V. If this same current is switched into an inductor, you could see a short voltage spike of up to 12 V. You should turn off the DC current by resetting the device or initiating the DMM for the capacitance or inductance measurement before switching to the channel.
- When you use the appropriate range for capacitance measurements, the voltage across the capacitor does not exceed 1 V. If you have a capacitor with a value lower than 5% of the range, you observe an <u>underrange</u> condition and can apply a test voltage exceeding the 1 V limit (maximum of 12 V). If the capacitor is not built to tolerate this voltage level, you could reduce its life, shift its value, or damage it permanently (less likely). When performing in-circuit testing, you could inadvertently bias other components in the circuit, such as transistors or diodes.
- After you take an inductance measurement or a resistance measurement on an inductive load, the excitation current remains

on. If the channel is opened immediately after you take the measurement, a voltage develops across the open circuit, because the inductor is still charged with current. This charge could produce a voltage across the open circuit that could shorten the life of the relays in the switch. To prevent damage to the setup, multiplexer, test fixture, or device under test, NI recommends performing one of the following actions before switching to the successive measurement:

- If the next measurement uses a function mode that requires a current excitation signal, turn off the current source by resetting the device immediately after taking the inductance measurement before breaking the channel.
- If the next measurement does *not* use a function mode that requires a current excitation signal (such as DC voltage), you can either reset the device or configure and initiate the next measurement before breaking the channel.

#### **Recommendations for System Integration**

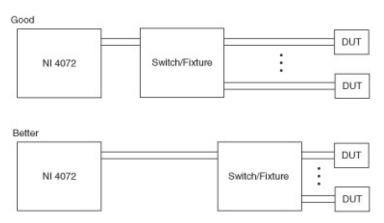
To integrate the NI 4072 into an ATE system, take the following steps to maximize your success:

- Keep cables as short as possible. Longer leads are more likely to introduce noise or errors into the system.
- Use twisted pairs or coaxial cable to reduce noise pickup.
- Use strain relief ties to maintain a consistent mechanical configuration.
- Minimize contact resistance everywhere a connection is present. Contacts should be firm and must be kept clean and free from oxides.
- Verify that the contact electrodes can be opened or shorted so that it is possible to perform <u>OPEN/SHORT compensation</u>.
  - Notes Components such as cables, switches, and fixtures can contribute noise to the measurement. Setting open or short conditions at the contact electrodes can minimize the noise effects of system components connected between the DMM and the DUT. To set a short condition, establish

direct contact at the end of the cable, or connect a short (<2 cm) AWG 18 gauge or thicker wire between the two conductors.

NI-DMM 2.3 or later allows you to save and load different compensation values per channel. To provide maximum flexibility in the test system, you can manipulate, store, and load these values for high channel-count systems.

 Minimize the variation of impedance between channels. If two channels have very similar impedance (for example, same cable type and length, and same type of switch path), one channel can perform the OPEN measurement and the other channel can perform the SHORT measurement. This multi-channel compensation is not as accurate as per-channel compensation, but multi-channel compensation can reduce test time and simplify the <u>OPEN/SHORT compensation</u> procedure for the other measurements. The impedance levels between all channels are more likely to be similar if all channels share the majority of the measurement path, as shown below:





**Notes** To determine what type of switch to use in your application, refer to <u>Using Switches</u>.

For recommendations about how to set up your scan list and configure your system, refer to <u>Load Switching</u>.

# Scanning

The NI 4060, NI 4065, and NI 4070/4071/4072 can exchange signals with NI switches during multipoint scanning operations. Two methods of scanning are available: <u>synchronous</u> and <u>handshaking</u>.

Refer to <u>Triggering</u> for programming flow information.

Refer to <u>Scanning Switch Modules</u> for information on trigger signals.

For switch configuration information and initial programming tips, refer to the *Scanning NI Switches with NI Digital Multimeters* section of the *NI Switches Help* (**Programming with NI-**

SWITCH»Features»Scanning»Scanning NI Switches with NI Digital Multimeters) at either of the following locations:

- Start»Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

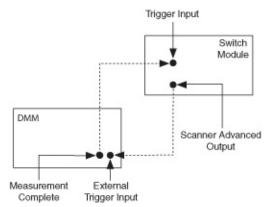
#### Scan List

A **scan list** is a string composed of channel names and characteristics that define connections, disconnections, triggering, and timing of the scan in the switch.

#### Handshaking Scanning

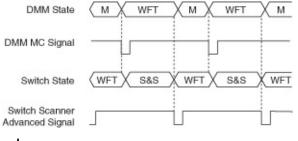
With handshaking, the DMM is initiated and waiting for a trigger. The switch module is initiated, executes the first connection in the <u>scan list</u>, and generates a digital pulse (Scan Advanced Output). The DMM receives this signal from the switch as an input trigger, takes a measurement, and then it generates a digital pulse—measurement complete (MC). When the switch receives the digital pulse, it advances to the next entry in its scan list. After the relays of the switch module have settled, the switch sends a digital pulse and triggers the DMM for a new measurement.

The following figure shows a DMM handshaking with a switch module.



# Handshaking Timing Diagram

The following figure shows the timing signals associated with the handshaking shown above.



#### where

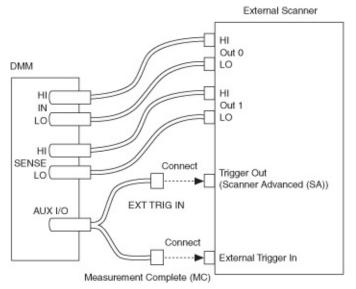
*M* = measurement

WFT = wait for trigger

S&S =switch and settle

# Hardware Connections to an External Multiplexer in Handshaking Mode

The following figure shows how to configure the hardware when performing handshaking between a DMM and an external multiplexer.



Refer to <u>Multiple Point Acquisitions</u> to determine your triggering options.

Refer to <u>Triggering</u> for more information:

- For programming flow, refer to <u>Single Point Acquisitions</u>, <u>Multi</u> <u>Point Acquisitions</u>, and <u>Continuous Acquisitions</u>.
- For information on available trigger sources and destinations when using National Instruments DMMs and switch modules, refer to <u>Scanning Switch Modules</u>.

For switch configuration information and initial programming tips, refer to the *Scanning NI Switches with NI Digital Multimeters* section of the *NI Switches Help* (**Programming with NI-**

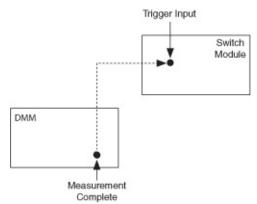
SWITCH»Features»Scanning»Scanning NI Switches with NI Digital Multimeters) at either of the following locations:

- Start»All Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

### Synchronous Scanning

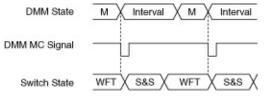
With synchronous scanning, the DMM takes a measurement and generates a digital pulse—measurement complete (MC). When the switch receives the digital pulse, it advances to the next entry in its <u>scan</u> <u>list</u>. The DMM takes the next measurement after a time interval. You must program the DMM interval time by configuring an Interval Sample Trigger. Set the **Interval** parameter to the time needed for the switch to activate and settle. Initiate the switch before initiating the DMM for its first measurement.

The following figure shows a DMM performing synchronous scanning with a switch module:



### Synchronous Scanning Timing Diagram

The following figure shows the timing signals associated with the synchronous scanning shown above:



where

*M* = measurement

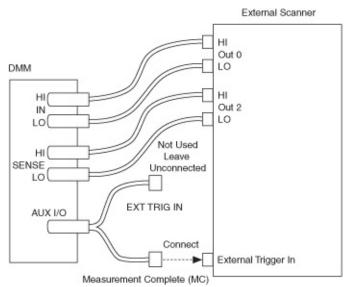
WFT = wait for trigger

S&S = switch and settle

# Hardware Connections to an External Multiplexer in Synchronous Mode

The following figure shows how to configure the hardware when

performing synchronous scanning between a DMM and an external multiplexer:



Refer to <u>Triggering</u> for more information:

- For programming flow, refer to <u>Single Point Acquisitions</u>, <u>Multi</u> <u>Point Acquisitions</u>, and <u>Continuous Acquisitions</u>.
- For information on available trigger sources and destinations when using National Instruments DMMs and switch modules, refer to <u>Scanning Switch Modules</u>.

For switch configuration information and initial programming tips, refer to the *Scanning NI Switches with NI Digital Multimeters* section of the *NI Switches Help* (**Programming with NI-**

SWITCH»Features»Scanning»Scanning NI Switches with NI Digital Multimeters) at either of the following locations:

- Start»All Programs»National Instruments»NI-SWITCH»Documentation»NI Switches Help (if you have installed NI-SWITCH)
- <u>NI Product Manuals Library</u> Web site (if you have *not* installed NI-SWITCH)

# **DMM Soft Front Panel**

You can use the DMM Soft Front Panel (DMM SFP) to take measurements and to test the functionality of the National Instruments DMMs. To launch the DMM SFP, navigate to **Start»All Programs»National Instruments»NI-DMM»NI-DMM Soft Front Panel**.

📅 NI USB-4065	
Eile Edit Utility Help	
INSTRUMENTS <sup>TM</sup>	Scaling mx+b Multiplier 1.00000
-000.0009 VDC Range : 100.00 VDC Resolution : 000.0001 VDC %FS	Offset 0.00000
DeviceUSB-4065; "Dev1"Range100 VVVAAHzResolution6.5 dig $\Omega$ $\Omega$ AHzHzMin Freq. $100.00$ $\Omega$ $\Omega$ CLHPower Line60 Hz	its I Offset Comp. Ohms Min/Max Hz Null Offset

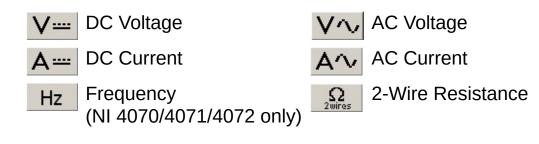
When using the DMM SFP, you have the option of making the following selections, based upon the measurement mode and functionality that your application requires:

• Select the DMM that you want to use.

Device	USB-4065: "Dev1"	•
Device	D20-4002: D6A1	

Tip If you cannot select the DMM you want to use, make sure it is available in Measurement & Automation Explorer (MAX).

• Select a measurement function.



4-Wire Resistance (NI 4050 <i>not</i> supported)	С	Capacitance (NI 4072 only)
L Inductance (NI 4072 only)	*	Diode
Select the range.		

Available ranges depend upon the DMM and the selected function that you are using. The range box displays a list of available ranges for each function and device. For most functions, you can also select Auto Range and let the device select a range for you. When you select Auto Range, resolution is also automatically selected and shown on the display. The input signal in relation to the selected range is represented on the display as a percentage of full scale.

%FS

- M
  - **Note** If the front panel displays OVLD, an overrange condition has occurred. If the front panel displays UNDRNG, an underrange condition has occurred.
- Select the resolution.

100 V

Range

-

Resolution 6.5 digits -Resolution: 000.0001 V DC

The maximum resolution depends upon the device that you are using.

M **Note** The NI 4065 and NI 4070/4072 have an available 6<sup>1</sup>/<sub>2</sub>-digit resolution. The NI 4071 only has an available 7<sup>1</sup>/<sub>2</sub>digit resolution for the resistance and DCV modes and an available 6<sup>1</sup>/<sub>2</sub>-digit resolution for all other measurement modes.

The display shows the resolution in absolute units. Refer to Resolution for more information.

 Select the powerline frequency that you want to reject. The NI 4060 and NI 4050 use this value to select an aperture time to reject powerline noise by selecting the appropriate internal sample clock and filter. The NI 4065 and NI 4070/4071/4072 use this value to select a timebase for setting the <u>Aperture Time</u> property in Powerline Cycles (PLCs).

Power Line	60 Hz	-
FOWER LINE		

• For AC and frequency measurements, set the minimum expected frequency of the input signal.

Min Freq. 🚦 1000.00 Hz

• Enable Auto Zero.

🔽 AutoZero

Auto Zero allows the DMM to compensate for any offsets in the measurement path or ADC. When Auto Zero is enabled, the internal DMM input HI is connected to its input LO and measured. The subsequent input signal is measured, and the Auto Zero value subtracted from it.



Notes The NI 4050 does not support Auto Zero.

For the NI 4065, Auto Zero is always ON. Auto Zero is an integral part of the signal measurement phase and adds no extra time to the overall measurement.

• Enable Offset Compensated Ohms (NI 4070/4071/4072 only).

Contract Comp. Ohms

Offset Compensated Ohms allows the DMM to eliminate voltage offsets in resistance measurements. When Offset Compensated Ohms is enabled, the DMM makes two resistance measurements (one with the current source n and the other with it turned off), and the second measurement is deducted from the first measurement. Any voltage offset present in both measurements is cancelled out. Offset Compensated Ohms is useful when measuring resistance values of less than 100  $\Omega$ .

• Perform cable compensation (NI 4072 only).



OPEN/SHORT Compensation allows you to minimize the errors between the NI 4072 and the DUT. You can choose to perform OPEN, SHORT, or both OPEN and SHORT cable compensation. Compensation consists of measuring the error and applying the measured error to the actual measurement to correct and minimize the errors introduced by the test system. The compensation functions must be set before taking any measurement at a specified function and range. Therefore, with any change in range or function, you must perform cable compensation again.

• Configure the display.



**Min/Max** displays the maximum and minimum values during the acquisition and is shown on the display. When enabled, the Min/Max display is reset to the latest value if the device, function, or range is changed.

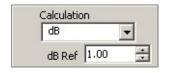


**Null Offset** stores the current reading of the DMM and subtracts it from any future readings. The stored offset is shown on the display. When enabled, the Null Offset value is updated if the device, function, or range is changed.

Filter

**Filter** allows the DMM SFP to display a running average of the measurements acquired. For AC measurements, eight readings are averaged. For DC measurements, four readings are averaged.

• Apply a calculation.



**dB** allows the input voltage to be compared to a reference voltage you select on a logarithmic scale and expressed in decibels. dB is defined in the following equation:

 $dB = 20 \log(V_{in}/Ref)$ 

where  $V_{in}$  is the DC or AC signal and *Ref* is the specified voltage reference level (db Ref).

Calculation
dBm 🗨
Ohms Ref 600.00

**dBm** is defined as decibels above or below a 1 mW reference. With a user-defined reference impedance (Ohms ref), DMM SFP reads 0 dBm when the voltage needed to dissipate 1 mW through the reference impedance is applied. The relationship between dBm, a reference impedance, and the voltage is defined by the following equation:

 $dBm = 10 \log((V_{in}^2)/(Ohms ref))/1 mW$ 

where  $V_{in}$  is the DC or AC input signal.

Calculatio	n	
Percent	age	•
% Ref	1.00	*

**Percentage** applies a percentage calculation. The displayed reading is expressed as a percent deviation from the reference value. The percentage calculation is performed as follows:

Percent = (Input—Ref)/(Ref) x 100

where *Input* is the normal display reading and *Ref* is the constant you select (% Ref).

• Apply **Scaling**. If a calculation or Null Offset is selected, these are applied before the measurement is scaled.

Scaling mx+b		
Multiplier	1.00000	÷
Offset	0.00000	÷

**Multiplier** (m) multiplies the reading by the number you select. For example, a 7 V reading with a scaling multiplier of 2 would read 14 V.

**Offset** (b) adds the number you enter to the reading. For example, a 7 V reading with an offset of 0.5 would read 7.5 V.

• Connect signals to your DMM. For signal connections, refer to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide*.

# Programming with NI-DMM

You can control your NI digital multimeter using the NI-DMM instrument driver.

### NI-DMM

NI-DMM, an Interchangeable Virtual Instrument (IVI)–compliant instrument driver, is included with your kit and communicates with all NI digital multimeters. NI-DMM features a set of operations and properties that exercise the functionality of the DMM hardware, including configuration, measuring, and scanning. In addition, NI-DMM comes with an interactive <u>Soft Front Panel</u>. NI-DMM eliminates the need to understand complex register programming and interrupt handling in the Microsoft operating systems, and frees you to focus on creating a test system.

#### **Making Signal Connections**

To acquire data, you need to connect the signals you want to measure to the DMM. For more information, click the link for your device.

NI PCMCIA-4050 Front Panel Connections

NI 4065 Front Panel Connections

NI 4060 Front Panel Connections

NI 4070 Front Panel Connections

NI 4071 Front Panel Connections

NI 4072 Front Panel Connections

#### Examples

Refer to <u>Getting Started</u> to begin controlling your DMM with NI-DMM. Refer to **Programming**»<u>Examples</u> for examples in NI LabVIEW, LabWindows/CVI, Visual C++, and Visual Basic.

# **Getting Started**

This topic explains how to begin using NI-DMM with your application development environment (ADE), lists any files to include in your application, and mentions special considerations to make with each ADE.

To successfully build your application, you need to have NI-DMM installed. You also need to have one of the following ADEs installed:

- LabVIEW
- LabWindows/CVI
- Visual C++
- <u>Visual Basic</u>

# Considerations for Using the LabVIEW Real-Time Module

To develop an NI-DMM application in the LabVIEW Real-Time Module, follow the same steps used for developing any application in the LabVIEW Real-Time Module, with the addition of using NI-DMM VIs.



**Note** Applications running NI-DMM in the LabVIEW Real-Time Module may be compromised and/or slow at 64 MB.

#### Hardware Support

You can use the following devices with the LabVIEW Real-Time Module:

- NI PXI-4072
- NI PXI-4071
- NI PXI-4070
- NI PXI-4065

#### **Unsupported Features**

When using National Instruments DMMs with the LabVIEW Real-Time Module, the following features are *not* supported:

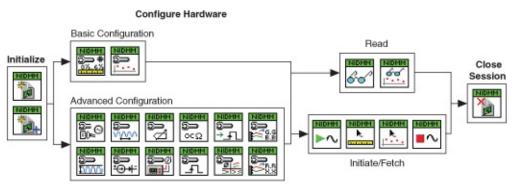
- External calibration
- Test panel
- DMM Soft Front Panel (DMM SFP)
- NI-DMM/Switch Express VI

#### **Related Documentation**

- For configuration instructions for remote systems, refer to the *Remote Systems Help* in Measurement & Automation Explorer (MAX) by selecting Help»Help Topics»Remote Systems in MAX.
- For more information on the LabVIEW Real-Time Module, refer to the *LabVIEW Real-Time Module User Manual* at the <u>NI Product</u> <u>Manuals Library</u> Web site.
- For additional troubleshooting and support information, refer to the <u>LabVIEW Real-Time Support</u> Web site.

# **Programming Flow**

The following diagram shows the basic programming flow of applications using NI-DMM. NI-DMM functions and VIs are organized under the Initialize, Configure Hardware, Read or Fetch Data, and Close categories to assist you in understanding where you should call a function or VI in your applications. Functions and VIs that do not fall into the programming flow are considered Utility functions that perform various tasks such as resetting the DMM, returning the revision number of the NI-DMM driver and instrument firmware, and other functions.



**Tip** If you are interested in configuring attributes or setting properties, refer to <u>Using Attributes and Properties with NI-DMM</u>.

## Initialize

For any application you write, you need to open a session to establish communication with the DMM by using <u>niDMM Initialize</u> or <u>niDMM</u> <u>Initialize with Options</u>.

P

**Tip** Do not confuse <u>niDMM Initialize</u> with <u>niDMM Initiate</u>. <u>niDMM</u> <u>Initiate</u> is used to start an asynchronous acquisition.

In addition to establishing a session with the DMM, <u>niDMM Initialize</u> also sends initialization commands to set the instrument to the state necessary for the operation of the instrument driver. <u>niDMM Initialize</u> can also perform a number of additional tasks such as verifying that the instrument driver is valid for the instrument and resetting the DMM to a known state. <u>niDMM Initialize</u> returns a ViSession handle that you use to identify the instrument in all subsequent NI-DMM calls.

<u>niDMM Initialize</u> and <u>niDMM Initialize With Options</u> create a new session. Repeated calls to <u>niDMM Initialize</u> for the same resource returns the existing session. You can use the same session in multiple program threads.

niDMM Initialize With Options performs all the functionality of niDMM Initialize and optionally sets the initial state of the DMM. With niDMM Initialize With Options, you can configure range checking, caching, coercion recording, simulation, and status reporting.

# **Configuring the Hardware**

The Configuration VIs and functions set up the acquisition. NI-DMM can configure single point measurements, multipoint measurements, and waveform acquisitions. The configuration functions depend on the type of acquisition used in an application.

To configure the DMM for a single point acquisition, call <u>niDMM Config</u> <u>Measurement</u> followed by calls to measurement options (such as <u>niDMM</u> <u>Configure Auto Zero Mode</u>, <u>niDMM Configure Power Line Frequency</u>, <u>niDMM Configure Offset Compensated Ohms</u>, etc).

	LabVIEW VIs	C and Visual Basic Functions
Configuration	niDMM Config Measurement	niDMM_ConfigureMeasurementDigits
Conngulation	<u>niDMM</u> Configure Multi Point	<u>niDMM_ConfigureMultiPoint</u>
	<u>niDMM</u> <u>Configure</u> <u>Waveform</u> Acquisition	<u>niDMM_ConfigureWaveformAcquisition</u>
	<u>niDMM</u> Configure AC Bandwidth	<u>niDMM_ConfigureACBandwidth</u>
	niDMM Configure ADC Calibration	niDMM_ConfigureADCCalibration
	<u>niDMM</u> Configure Auto Zero	<u>niDMM_ConfigureAutoZeroMode</u>
Measurement Options	<u>niDMM</u> <u>Configure</u> <u>Cable Comp</u> Type	niDMM_ConfigureCableCompType
Ομιστις	<u>niDMM</u>	niDMM_ConfigureCurrentSource

The following table lists VIs and functions for configuring the DMM:

	<u>Configure</u> <u>Current Source</u>	
	<u>niDMM</u> <u>Configure</u> <u>Frequency</u> <u>Voltage Range</u>	<u>niDMM_ConfigureFrequencyVoltageRange</u>
	<u>niDMM</u> <u>Configure</u> <u>Offset Comp</u> <u>Ohms</u>	<u>niDMM_ConfigureOffSetCompOhms</u>
	<u>niDMM</u> Configure Open Cable Comp Values	niDMM_ConfigureOpenCableCompValues
	niDMM Configure Powerline Frequency	niDMM_ConfigurePowerlineFrequency
	niDMM Configure Short Cable Comp Values	niDMM_ConfigureShortCableCompValues
	niDMM Configure Waveform Coupling	niDMM_ConfigureWaveformCoupling
	niDMM Configure Meas Complete Dest	niDMM_ConfigureMeasCompleteDest
Trigger	niDMM Config Measurement Complete Slope	niDMM_ConfigureMeasCompleteSlope
	<u>niDMM</u> <u>Configure</u> <u>Sample Trigger</u> <u>Slope</u>	niDMM_ConfigureSampleTriggerSlope

<u>niDMM</u> <u>Configure</u> Trigger	<u>niDMM_ConfigureTrigger</u>
<u>niDMM</u> <u>Configure</u> <u>Trigger Slope</u>	niDMM_ConfigureTriggerSlope

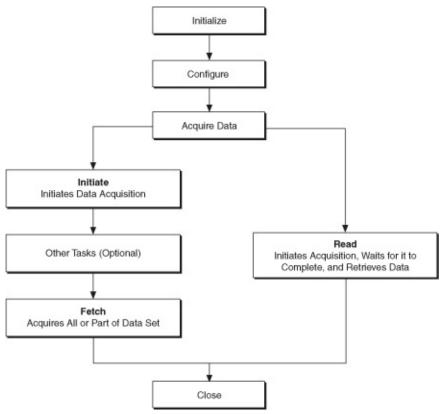
#### **Advanced Attributes and Properties**

Some advanced attributes and properties are not available through a configuration function or VI. Set the attributes and properties directly using the <u>niDMM\_SetAttributeViReal64</u> function or a property node. Refer to <u>Using Attributes and Properties with NI-DMM</u> for more information on attribute and property programming. Refer to the following table for a list of those attributes and properties configurable only through the <u>niDMM\_SetAttributeViReal64</u> function or a property node.

LabVIEW Property	C and Visual Basic Attribute
Aperture Time	NIDMM_ATTR_APERTURE_TIME
<u>Aperture Time</u> <u>Units</u>	NIDMM_ATTR_APERTURE_TIME_UNITS
DC Noise Rejection	NIDMM_ATTR_DC_NOISE_REJECTION
Input Resistance	NIDMM_ATTR_INPUT_RESISTANCE
Latency	NIDMM_ATTR_LATENCY
<u>Number of</u> Averages	NIDMM_ATTR_NUMBER_OF_AVERAGES
Number of LC Measurements to Average	NIDMM_ATTR_LC_NUMBER_MEAS_TO_AVERAGE
Operation Mode	NIDMM_ATTR_OPERATION_MODE
Settle Time	NIDMM_ATTR_SETTLE_TIME
Shunt Value	NIDMM_ATTR_SHUNT_VALUE

# **Acquiring Data**

After you have configured the acquisition, you can acquire data by calling <u>niDMM Read</u> or <u>niDMM Initiate</u> and <u>niDMM Fetch</u>.



#### Read

niDMM Read initiates an acquisition, reads the acquired data, stops the acquisition, and returns control to your program. <u>niDMM Read</u> does not return control to your program until all of the requested data has been acquired. If you have not configured a trigger, the DMM immediately begins its acquisition and acquires a measurement. Refer to <u>Single Point</u> Acquisitions for information on triggering options.

You can set the maximum length of time (**Maximum Time**) to allow the measurement operation to complete. If the measurement operation does not complete within this time interval, <u>niDMM Read</u> returns an error.

#### **Initiate and Fetch**

Use <u>niDMM Initiate</u> and <u>niDMM Fetch</u> for a more flexible method for acquiring data, offering several advantages over <u>niDMM Read</u>. With <u>niDMM Initiate</u>, you can perform other operations while the DMM

acquires data. niDMM Fetch retrieves the acquired data.

After executing <u>niDMM Initiate</u>, the DMM begins acquiring data and sending it to your computer RAM. Meanwhile, control is returned immediately to your program, which frees up the computer processor for other tasks.

After <u>niDMM Initiate</u>, call <u>niDMM Fetch</u>; <u>niDMM Fetch</u> waits until the requested data has been acquired. <u>niDMM Fetch</u> transfers the acquired data from memory to your application. If the data is not acquired within the time specified with the timeout parameter, NI-DMM returns an error. If you want to stop the DMM before it finishes, use <u>niDMM Abort</u>.



**Tip** Use <u>niDMM Read Status</u> before calling <u>niDMM Fetch</u> to determine the number of measurements available.



**Note** <u>niDMM Read</u> combines <u>niDMM Initiate</u> and <u>niDMM Fetch</u> into one call. <u>niDMM Read</u> is suitable for simple acquisitions. <u>niDMM Initiate/niDMM Fetch</u> is better suited for complex applications that involve scanning and/or triggering.

#### **Multi Point Acquisitions**

Call <u>niDMM Read Multi Point</u> or <u>niDMM Initiate</u> and <u>niDMM Fetch Multi</u> <u>Point</u> for multipoint acquisitions. If the measurement operation does not complete within the **Maximum Time** interval, <u>niDMM Read Multi Point</u> or <u>niDMM Fetch Multi Point</u> returns any acquired data along with a timeout error.

 $\overline{\mathbb{N}}$ 

Note If you are programming in C or Visual Basic and are acquiring multiple data points, you need to declare an array in your program. This array allocates space for the data that is acquired with <u>niDMM Fetch Multi Point</u> or <u>niDMM Read Multi Point</u>.
 LabVIEW users do not need to declare an array because <u>niDMM Fetch Multi Point</u> and <u>niDMM Read Multi Point</u> handles the array.

#### **Waveform Acquisitions**

The NI 4070/4071/4072 has a digitizer that can be used to capture waveforms.

Use <u>niDMM Configure Waveform Acquisition</u> to configure the acquisition and <u>niDMM Read Waveform</u> or <u>niDMM Initiate</u> and <u>niDMM Fetch</u> <u>Waveform</u> to retrieve the waveform data.



**Note** If you are programming in C or Visual Basic, you need to declare an array in your program. This array allocates space for the data that is acquired with <u>niDMM Read Waveform</u> or <u>niDMM</u> <u>Fetch Waveform</u>. LabVIEW users do not need to declare an array because <u>niDMM Read Waveform</u> and <u>niDMM Fetch Waveform</u> handles the array.

You can set the maximum length of time (**Maximum Time**) to allow the measurement operation to complete. If the measurement operation does not complete within this time interval, <u>niDMM Read Waveform</u> or <u>niDMM</u> <u>Fetch Waveform</u> returns any acquired data along with the error.

#### Combining Single Point Measurements, Multiple Point Measurements, and Waveform Acquisitions in the Same Session

You can combine multiple types of acquisitions in the same session. For example, you can open a session, read a single point, and then acquire a waveform. You can also alternate between single and multiple point measurements, and you can change the configuration and acquire a resistance measurement after taking a voltage measurement.

The <u>Operation Mode</u> property controls whether the DMM takes standard single or multi point measurements, or acquires a waveform.

The driver sets the value of this property when you call <u>niDMM Config</u> <u>Measurement</u> or <u>niDMM Configure Waveform Acquisition</u>. The <u>Operation</u> <u>Mode</u> property is set to IVIDMM MODE when <u>niDMM Config</u> <u>Measurement</u> is called. The driver takes a single point measurement if the Trigger Count and niDMM Sample Count properties are both set to 1. If either of these values has been changed, either by calling <u>niDMM</u> <u>Configure Multi Point</u> or by setting the properties directly, the driver takes a multipoint measurement. The <u>Operation Mode</u> property is set to WAVEFORM MODE when <u>niDMM Configure Waveform Acquisition</u> is called.

If you are programming with properties or attributes, you should set the <u>Operation Mode</u> property to the correct value before setting other properties for that configuration.

## Close

When your program finishes, terminate the session with <u>niDMM Close</u>.

<u>niDMM Close</u> is essential for freeing resources, including deallocating memory, destroying threads, and freeing operating system resources. Every session that you initialize must be closed, even if an error occurs during your program. While debugging your application, you can abort execution before it reaches <u>niDMM Close</u>. While aborting execution should not cause problems, it is not recommended.

# **Using Attributes and Properties with NI-DMM**

NI-DMM contains high-level functions and VIs that set most of the instrument attributes. Use the high-level driver functions and VIs as much as possible, because they handle order dependencies and multithread locking for you.

Some attributes and properties are not accessible through the high-level functions or VIs. For example, **Input Resistance** is not set with any of the NI-DMM configuration functions or VIs. The values for these attributes and properties must be set using the attribute or property.

#### **Accessing Attributes and Properties**

In LabVIEW, properties are accessed through the NI-DMM property node. To access them, complete the following steps:

- 1. Open a VI.
- 2. Make sure that you are viewing the block diagram. Navigate to the NI-DMM palette at **Instrument I/O»Instrument Drivers»NI-DMM**, and drag the property node icon to the diagram.
- 3. Select the correct property node class by wiring an **instrument handle in** into the property node reference, or by right-clicking on the property node and choosing **Select Class»IVI»niDMM**.
- 4. Left-click the property node, and select the property you want to use.
- 5. To add additional properties, resize the property node.

In C and Visual Basic, attributes are accessed with the Get Attribute and Set Attribute functions. These functions correspond to a particular data type. To set the <u>NIDMM\_ATTR\_INPUT\_RESISTANCE</u> attribute, use the <u>niDMM\_SetAttributeViReal64</u> function.

The defined properties values are not always equivalent to the values used in LabVIEW enumeration controls. In NI-DMM VIs, the first value for LabVIEW enumerations always begins at zero. For example, If you use niDMM Config Measurement to set the VI to DC volts, this value is zero. This value is translated before being passed to the driver. If you use the property node to configure the VI, DC volts is set with IVIDMM VAL DC VOLTS = 1.

To translate between LabVIEW enumerated values and IVI constants,

use the conversion VIs in LabVIEW located in the NI-DMM.llb. Refer to the <u>LabVIEW VI Reference</u> or <u>Function Reference</u> for a complete listing of available attributes.

# Features

This topic explains how to program additional features of the DMMs. The following table is a quick overview of the additional features supported by NI digital multimeters. Click the feature for programming instructions.

Features	NI 4070/4071/4072	NI 4065	NI 4060	NI 4050
Performing Self- Calibration	$\checkmark$			
Configuring Auto Zero	$\checkmark$	$\checkmark$	$\checkmark$	
Configuring Auto Range	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
Configuring Offset Compensated Ohms	$\checkmark$			
Configuring Input Resistance	$\checkmark$	$\checkmark$		
Configuring ADC Calibration	$\checkmark$			
Configuring Measurement Timing	$\checkmark$	$\checkmark$	$\checkmark$	
Selecting DC Noise Rejection	$\checkmark$	$\checkmark$		
Acquiring Waveforms	$\checkmark$			
Configure Waveform Coupling	$\checkmark$			
Configuring Frequency Measurements	$\checkmark$			
Configuring Period Measurements	$\checkmark$			
Single Point Acquisitions	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
Multiple Point Acquisitions	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
Generating Measurement Complete	$\checkmark$	$\checkmark$	$\checkmark$	
Scanning Switch Modules	$\checkmark$	$\checkmark$	$\checkmark$	

Simulating NI Digital Multimeters	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
LabVIEW Trigger Routing	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
LabWindows/CVI Trigger Routing	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$

# **Performing Self-Calibration**

For the NI 4070/4071/4072 only, run the <u>self-calibration</u> routine:

LabVIEW—Use <u>niDMM Self Cal</u>.

CVI, C++, or Visual Basic—Use <u>niDMM\_SelfCal</u>.

# **Configuring Auto Zero**

To enable, enable once, or disable <u>Auto Zero</u>:

Note The NI 4050 does *not* support Auto Zero.

LabVIEW—Use niDMM Configure Auto Zero.

CVI, C++, or Visual Basic—Use <u>niDMM\_ConfigureAutoZeroMode</u>.

AUTO (default)	-1	NI-DMM chooses the Auto Zero setting based on the configured function and resolution.
OFF	0	Disables Auto Zero.
ON	1	<ul> <li>The DMM internally disconnects the input signal following each measurement and takes a zero reading. It then subtracts the zero reading from the preceding reading.</li> <li>Note For NI 4065 devices, Auto Zero is always ON. Auto Zero is an integral part of the signal measurement phase and adds no extra time to the overall measurement.</li> </ul>
ONCE	2	<ul> <li>The DMM internally disconnects the input signal for the first measurement and takes a zero reading. It then subtracts the zero reading from the first reading and the following readings.</li> <li>Note The NI 4060/4065 does <i>not</i> support this setting.</li> </ul>

# **Configuring Auto Range**

Auto Range allows you to measure a signal when you do not know which range to select. The DMM takes a series of measurements and adjusts the range until the measurement falls within the smallest range appropriate for that measurement.

Auto Range uses the same configuration as 5½–digit measurements. Refer to the <u>NI 4065 DMM Measurement Defaults</u> or the <u>NI 4070/4071/4072 DMM Measurement Defaults</u> for more information on the configuration of Auto Range measurements.

### Notes

- Auto Range does not adjust for the extended 200 M $\Omega$  range in 2-wire resistance measurements. You must specify the 200 M $\Omega$  range on the NI 4050 and NI 4060.
- Auto Range is unavailable during diode measurements and waveform acquisitions on NI 407*x* devices.
- Auto Range reduces the reading rate of your measurements because the DMM takes an Auto Range reading before each measurement.
- The NI 4050, NI 4060, and NI 4065 only support Auto Range when the trigger and sample trigger are set to IMMEDIATE.
- DC current Auto Range on the NI 4071 does *not* support the 1  $\mu$ A and 10  $\mu$ A ranges; for low currents, the NI 4071 only Auto Ranges down to 100  $\mu$ A. This behavior prevents an electromechanical relay from switching between these ranges (especially when high-compliance voltages could be present) thereby lengthening the life of the relay.

To enable Auto Range, complete the following steps:

- LabVIEW
  - 1. Insert <u>niDMM Config Measurement</u> into the block diagram.
  - 2. Set **Range** to the desired Auto value (refer to the following table).
- CVI/C++/Visual Basic

- 1. Use <u>niDMM\_ConfigureMeasurementDigits</u>.
- 2. Set **Range** to the desired Auto Range value (refer to the following table).

Values	Description
•	An Auto Range measurement is performed prior to each measurement.
OFF (– 2)	Use after a measurement that used Auto Range ON to set the DMM to the currently selected range.
	NI-DMM picks a range for the first point and uses that range for the remaining measurements.

Tip Use <u>niDMM Get Auto Range Value</u> or <u>niDMM\_GetAutoRangeValue</u> to retrieve the actual range used for a measurement.

### **Configuring Offset Compensated Ohms**

By default, <u>offset compensated ohms</u> is disabled. For the 4070/4071/4072 only, enable or disable offset compensated ohms by choosing one of the following:

LabVIEW—Use niDMM Configure Offset Comp Ohms.

CVI, C++, or Visual Basic—Use <u>niDMM\_ConfigureCompOhms</u>.

# **Configuring ADC Calibration**

For the NI 4070/4071/4072 only, configure <u>ADC calibration</u> by completing the following steps:

- LabVIEW
  - 1. Insert <u>niDMM Configure ADC Calibration</u> into the block diagram.
  - 2. Set **ADC Calibration** to the desired input value (refer to the following table).
- CVI/C++/Visual Basic
  - 1. Insert <u>niDMM\_ConfigureADCCalibration</u> into the program.
  - 2. Set **ADC Calibration** to the desired input value (refer to the following table).

Values	Description
	The driver chooses the ADC calibration setting based on the configured function and resolution.
ON (1)	Enables ADC Calibration.
OFF (0)	Disables ADC Calibration.

# **Configuring Input Resistance**

Select the *input resistance* by choosing one of the following:

**LabVIEW**—Use the <u>Input Resistance</u> property to set the input resistance.

**CVI, C++, or Visual Basic**—Use <u>niDMM\_SetAttributeViReal64</u> to set the desired value for the <u>NIDMM\_ATTR\_INPUT\_RESISTANCE</u> attribute.



**Note** The NI 4050 and NI 4060 are not supported

### **Selecting DC Noise Rejection**

Select the <u>DC noise rejection</u> setting by choosing one of the following:

LabVIEW—Set the <u>DC Noise Rejection</u> property.

CVI, C++, or Visual Basic—Set the <u>NIDMM\_ATTR\_DC\_NOISE\_REJECTION</u> attribute.

Note The NI 4050 and NI 4060 are not supported.

By default, DC Noise Rejection is set to Auto Selection (-1). When the value is Auto, the driver selects the DC Noise Rejection setting based on the resolution you configure. If you configure the NI 4070/4071/4072 with an absolute resolution that corresponds to 6½ digits (NI 4070/4072) or 7½ digits (NI 4071 only), the driver uses high-order DC noise rejection. If you configure the NI 4065 with an absolute resolution that corresponds to 6½ digits, the driver uses second-order DC noise rejection. For lower resolution DC measurements, the driver uses second-order DC noise rejection for the NI 4070/4071/4072 and normal DC noise rejection for the NI 4065. If you set the aperture time or configure the device for a waveform acquisition, the driver uses normal DC noise rejection by default. For AC measurements with the NI 4065, the driver uses second-order DC noise rejection.

Refer to **DMM Measurement Defaults** for more information.

Values	Description
AUTO (-1)	The driver chooses the DC noise rejection setting based on the configured function and resolution.
Normal (0)	NI-DMM weighs all samples equally.
Order	NI-DMM weighs the samples taken in the middle of the aperture time more than samples taken at the beginning and the end of the measurement.

High- Order	NI-DMM weighs the samples taken in the middle of the aperture time more than samples taken at the beginning and
(2)	the end of the measurement.
	Note The NI 4065 does not support High-Order.

# **Configure Waveform Coupling**

For the NI 4070/4071/4072 only, configure the coupling for a voltage waveform acquisition by choosing one of the following:

LabVIEW—Use niDMM Configure Waveform Coupling.

**CVI, C++, or Visual Basic**—Use <u>niDMM\_ConfigureWaveformCoupling</u> function.

Values	Description
AC (1)	Configures AC coupling of the input signal.
DC (0)	Configures DC coupling of the input signal.

# **Configuring Frequency Measurements**

For the NI 4070/4071/4072 only, to configure a <u>frequency measurement</u>, complete the following steps:



**Note** If you specify Auto Range (-1.0) for the frequency range, the DMM defaults to 1 Hz, which has a 2 second aperture.

#### • LabVIEW

- 1. Use <u>niDMM Config Measurement</u>.
- 2. Set Measurement Function to Frequency.
- 3. Set **Range** to specify the minimum AC frequency. The DMM uses the range to calculate the aperture time.
- 4. Use <u>niDMM Configure Frequency Voltage Range</u>.
- 5. Set **Frequency Voltage Range** to the AC V range of your input signal.
- CVI/C++/Visual Basic
  - 1. Use <u>niDMM\_ConfigureMeasurementDigits</u>.
  - 2. Set **Measurement Function** to NIDMM\_VAL\_FREQ.
  - 3. Set **Range** to specify the minimum AC frequency. The DMM uses the range to calculate the aperture time.
  - 4. Use <u>niDMM\_ConfigureFrequencyVoltageRange</u>.
  - 5. Set **Frequency Voltage Range** to the AC V range of your input signal.

# **Configuring Period Measurements**

For the NI 4070/4071/4072 only, configure a period measurement by completing the following steps:



**Note** If you specify Auto Range (-1.0) for the period range, the DMM defaults to a 2 second aperture time.

#### • LabVIEW

- 1. Use niDMM Config Measurement.
- 2. Set Measurement Function to Period.
- 3. Set **Range** to the maximum expected period in seconds. The DMM uses the range to calculate the aperture time.
- 4. Use <u>niDMM Configure Frequency Voltage Range</u>.
- 5. Set **Frequency Voltage Range** to the AC V range of your input signal.
- CVI/C++/Visual Basic
  - 1. Use <u>niDMM\_ConfigureMeasurementDigits</u>.
  - 2. Set **Measurement Function** to NIDMM\_VAL\_PERIOD.
  - 3. Set **Range** to the maximum expected period in seconds. The DMM uses the range to calculate the aperture time.
  - 4. Use <a href="mailto:niDMM\_ConfigureFrequencyVoltageRange">niDMM\_ConfigureFrequencyVoltageRange</a>
  - 5. Set **Frequency Voltage Range** to the AC V range of your input signal.

# **Simulating NI Digital Multimeters**

You can simulate your DMM. This is particularly useful if you are developing your applications and the hardware you are using is unavailable.

To simulate a device, complete the following steps:

- LabVIEW
  - 1. Use <u>niDMM Initialize With Options</u>.
  - 2. Add "Simulate=1,DriverSetup=Model:[4050, 4060, 4065, 4070, 4071, 4072]; BoardType:[PCMCIA, PCI, PCIe, PXI, USB]" to the Option String of the VI.
- CVI/C++/Visual Basic
  - 1. Use <u>niDMM\_InitWithOptions</u>.
  - Add "Simulate=1,DriverSetup=Model:[4050, 4060, 4065, 4070, 4071, 4072]; BoardType:[PCMCIA, PCI, PCIe, PXI, USB]" to the Option String of the function.

For example, to simulate the NI PCI-4065, the option string would be:

"Simulate=1, DriverSetup=Model:4065; BoardType:PCI"

**Supported Combinations** 

Model	Board Type
4050	PCMCIA
4060	PXI, PCI
4065	PXI, PCI, PCIe, USB
4070	PXI, PCI
4071	PXI
4072	PXI

If the **Instrument Descriptor** parameter and the <u>Driver Setup</u> property are not specified, an NI PXI-4070 is simulated by default. If the <u>Driver</u> <u>Setup</u> string is not provided, and the **Instrument Descriptor** parameter specifies a valid device, the device of the **Instrument Descriptor** property is simulated. If the <u>Driver Setup</u> string is specified, the **Instrument Descriptor** property is ignored.

### **Measuring Current**

This section describes how to measure current on National Instruments DMMs.

# Measuring Current Within the Normal Range (NI 4050 is not supported)

To configure current measurements within the normal range on the NI 4060, the NI 4065, and the NI 4070/4071/4072, use one of the following two methods:

#### Method 1

- 1. Select the current measurement function.
- 2. Take a reading from the NI 4060, the NI 4065, or the NI 4070/4071/4072 immediately.

#### Method 2

- 1. Configure the DMM for a software trigger.
- 2. Initiate the DMM for a current measurement to cause the input relay to switch.
- 3. Send a software trigger to the DMM to take a measurement.

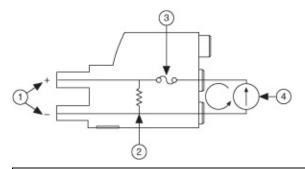
#### **Using Current Shunt Modules**

When taking current measurements outside of the specified range on the DMM, and when taking any current measurements on the NI 4050, you must use a current shunt module. NI offers the NI CSM-10A and the NI CSM-200mA current shunt modules. The NI CSM-10A has a 0.01  $\Omega$  sense resistor, and the NI CSM-200mA has a 1.0  $\Omega$  sense resistor.



**Note** For the valid current ranges on the NI 4060/4065 and NI 4070/4071/4072, refer to <u>Related Documentation</u> for the specifications documents.

Each current shunt module (CSM) operates by passing the input current through a precise resistor. The following figure shows the internal circuitry of the CSM:



**1** Voltage Across Resistor (V<sub>OUT</sub>) **3** Fuse

**2** Precision Resistor

**4** Current Source  $(I_{IN})$ 

To configure current measurements using the NI CSM-200mA or the NI CSM-10A, perform one of the following two methods:

Method 1
<b>Note</b> This method is valid for all National Instruments DMMs. Use the NI CSM-10A current shunt with the NI 4060/4065 or NI 4070/4071/4072. Use the NI CSM-10A current shunt or the NI CSM-200mA current shunt with the NI 4050.
<ol> <li>Measure the voltage drop across the resistor of the CSM.</li> <li>Use this value to calculate the current using Ohm's Law, as follows:</li> </ol>
$I_{\rm IN} = (V_{\rm OUT})/R$
where
<i>I</i> is the input current
V is the voltage across the precision resistor
R is the resistance of the precision resistor
For example, assume that you are using the CSM-200mA, which has a 1 $\Omega$ precision resistor, and the measured voltage is 50 mV. Apply these values to Ohm's Law to determine the current, as follows:

50 mA = 50 mV / 1  $\Omega$ 

Method 2 (NI 4050 only)

LabVIEW	C/C++/CVI/Visual Basic
1. Call <u>niDMM Config</u> <u>Measurement</u> .	1. Call <u>niDMM_ConfigureMeasurementDigits</u> .
<ul> <li>2. Specify the shunt value in the <u>Shunt</u> Value property node.</li> <li>3. Call <u>niDMM Read</u> to obtain the value of the measurement.</li> </ul>	<ol> <li>Specify the shunt value in the <u>NIDMM_ATTR_SHUNT_VALUE</u> attribute.</li> <li>Call <u>niDMM_Read</u>.</li> </ol>

# Triggering

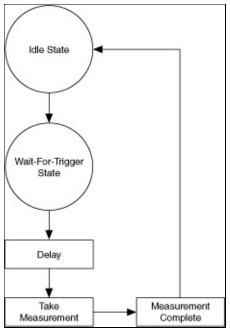
Triggering is a feature that allows you to take a measurement on demand. For example, if you are scanning with a switch, you may want to trigger the DMM to take a measurement after the switch has been activated and settled. To understand triggering, knowledge of the DMM behavior during an acquisition is required.

Refer to the *Triggering* sections for the <u>NI 4070/4071/4072</u>, the <u>NI 4065</u>, and the <u>NI 4060</u> for pin assignments and cable accessory information.

This section includes:

- Single Point Acquisitions
- Multi Point Acquisitions
- <u>Continuous Acquisitions</u>
- <u>Generating Measurement Complete</u>
- <u>Scanning Switch Modules</u>
- LabVIEW Trigger Routing
- LabWindows/CVI Trigger Routing

# **Single Point Acquisitions**



To configure a single point acquisition, use <u>niDMM Config Measurement</u>, which configures the DMM for a single point acquisition by default. This function allows you to configure the function, range, and resolution. Refer to <u>Configuring the Hardware</u> for more information.

Initiate a single point acquisition by calling either <u>niDMM Initiate</u> or <u>niDMM Read</u>. The DMM enters the Idle state after <u>niDMM Initiate</u> is called.



**Note** <u>niDMM Read</u> combines <u>niDMM Initiate</u> and <u>niDMM Fetch</u> into one call. Refer to <u>Acquiring Data</u> for more information.

In single point acquisitions, you can configure the DMM to wait for a trigger before taking a measurement. You can also specify a delay between when the DMM receives the trigger and when it acquires the measurement. Use <u>niDMM Configure Trigger</u> to set the **Trigger Source** and **Trigger Delay**.

By default, the **Trigger Delay** is Auto Delay (-1), which means the DMM waits an appropriate settling time before taking the measurement. The following table contains additional information about the **Trigger Delay** setting for the DMMs:

Device	Description

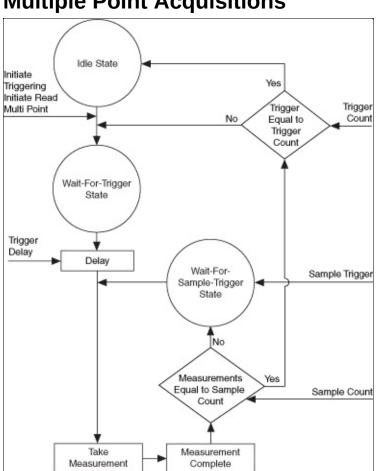
If <b>Trigger Delay</b> is set to 0, the DMM does not settle before taking the measurement.
The DMM uses the value specified in <b>Trigger Delay</b> as additional settling time as demonstrated in the
Acq One Sample-Ext Trig example.



Note If you do not configure a trigger source, Immediate is used as the default setting. To determine which values are supported by each device, refer to the LabVIEW Trigger Routing section.

Refer to Scanning Switch Modules for more information about possible trigger sources.

After taking the measurement, the DMM can generate a Measurement <u>Complete</u> signal. The DMM then returns to the Idle state.



#### **Multiple Point Acquisitions**

To configure multiple point acquisitions, first configure the function, range, and resolution with niDMM Config Measurement, and then configure the number of points to acquire with niDMM Configure Multi Point. Multiple point acquisitions are useful when you need to acquire multiple measurements with the same configuration.

For multiple point acquisitions, the DMM recognizes two different triggers, which are called trigger and sample trigger. The number of times a trigger is received is specified as a count. The **Trigger Count** and **Sample Count** parameters specify the count for each type of trigger. The total number of samples acquired is equal to the product of Trigger Count and Sample Count.

Configure the trigger source with <u>niDMM Configure Trigger</u> and the trigger source polarity with <u>niDMM Configure Trigger Slope</u>. Use <u>niDMM</u> Configure Multi Point to configure the sample trigger source, trigger count, and sample count. Use <u>niDMM Configure Sample Trigger Slope</u> to configure the sample trigger polarity.

As explained in <u>Single Point Acquisitions</u>, different sources are available for the trigger source. In a similar manner, the sample trigger also has different source options. Refer to <u>niDMM Configure Trigger</u> and <u>niDMM</u> <u>Configure Multi Point</u> for the possible trigger sources.

The acquisition is initiated when <u>niDMM Initiate</u> or <u>niDMM Read Multi</u> <u>Point</u> is called.



Note <u>niDMM Read Multi Point</u> combines <u>niDMM Initiate</u> and <u>niDMM Fetch Multi Point</u> into one call. Refer to <u>Acquiring Data</u> for more information.

The DMM enters the Wait-for-Trigger state. When the trigger is received on the specified trigger source, the DMM waits for the specified trigger delay and then takes the first measurement. If **Sample Count** is greater than 1, the DMM enters the Wait-for-Sample-Trigger state. When the sample trigger is received on the appropriate sample trigger source, the DMM takes the next measurement. The DMM remains in the Sample Trigger loop until the measurement count is equal to the sample count. The DMM then compares the number of triggers received to the requested **Trigger Count**. If the number of triggers received is less than the **Trigger Count**, the DMM returns to the Wait-For-Trigger state and repeats the measurement process as described above. When the DMM has received the requested number of triggers for the sample trigger and the trigger, it returns to the Idle State.

Based upon the needs of your application, choose appropriate sources and counts for each trigger, as follows:

- If you require a multiple point acquisition with each measurement triggered by the same signal, you can set the Trigger Count equal to one and set the Sample Count to the total number of measurements. Specify the same source of the trigger for both the Trigger Source parameter of niDMM Configure Trigger and the Sample Trigger parameter of niDMM Configure Multi Point. For a demonstration, refer to the example Acq Multiple Samples-Ext Trig-Ext Sample Trig.
- If you need to initiate an acquisition with a single digital trigger and then acquire multiple measurements without triggering, set the source of the trigger in the **Trigger Source** parameter of

niDMM Configure Trigger to the appropriate digital line, set the **Trigger Count** to 1, set the **Sample Trigger** to Immediate, and set the **Sample Count** to the desired number of measurements. For a demonstration, refer to the example <u>Acq Multiple Samples-Ext Trig</u>.

- If you want to insert a delay between measurements in the sample loop, set the **Sample Trigger** to Interval and specify the delay in seconds for the **Sample Interval** parameter. For a demonstration, refer to the example <u>Acq Multiple Samples-Interval Sample Trig</u>.
- If you want to control the acquisition using Software timing, configure the Trigger Source and/or Sample Trigger to Software. Use <u>niDMM Send Software Trigger</u> to send a trigger to the DMM. For a demonstration, refer to the example <u>Cont Acq</u> <u>Multiple Samples-SW Sample Trig</u>.

Refer to <u>Scanning Switch Modules</u> for more information about possible trigger sources.

After taking the measurement, the DMM can generate a <u>Measurement</u> <u>Complete</u> signal. The DMM then returns to the Idle State.

# **Continuous Acquisitions**

Continuous acquisitions function the same way as <u>multi point acquisitions</u> except that the trigger loop or the sample trigger loop are continuous. To configure a continuous acquisition, set **Trigger Count** or **Sample Count** to 0.

- Setting **Sample Count** to 0 causes the conditional statement "Measurements equal to Sample Count" to always evaluate to False. The DMM continues taking measurements in the inner loop.
- Setting **Trigger Count** to 0 causes the conditional statement "Triggers equal to Trigger Count" to always evaluate to False.



**Notes** To take continuous measurements on the NI 4060 or NI 4050, set **Sample Count** to 0. **Trigger Count** can only be equal to 1 for these DMMs.

Continuous acquisitions cannot be performed using waveform mode.

To end a continuous acquisition, you must call <u>niDMM Abort</u>.

## **Generating Measurement Complete**

The NI 4060/4065 and NI 4070/4071/4072 can generate a trigger after taking a measurement. This digital trigger is called Measurement Complete (MC), and can be routed to destinations including PXI trigger lines (TTL*n*) (NI PXI-4060/4065 and NI PXI-4070/4071/4072 only) and the external 9-pin AUX connector. You can configure the destination of the trigger using niDMM Configure Meas Complete Dest. Refer to niDMM Configure Meas Complete Dest for all of the destination options for MC.

Note If the NI 4060 is controlling SCXI through the front panel connectors, the MC signal is routed to External by default. If it is controlling SCXI through the internal PXI/SCXI communication lines, the MC signal is routed by default to TTL0, which in turn is routed to an internal PXI/SCXI line. If the NI 4060 is not controlling SCXI, the default setting for the MC signal is None.

One reason for generating a trigger after every measurement is to trigger a switch module to advance to the next entry in its <u>scan list</u>.

You can configure the polarity of the MC signal using <u>niDMM Configure</u> <u>Meas Complete Slope</u>. Set **Slope** to Positive or Rising Edge to generate an MC signal that pulses high. Set **Slope** to Negative or Falling Edge to generate an MC signal that pulses low. Switches generally can only be triggered on Falling Edge.

Refer to <u>Scanning Switch Modules</u> for more information about using MC in a switching system.



**Note** For waveform acquisitions, the MC signal is generated after the entire waveform is acquired, not after each point.

# **Scanning Switch Modules**

The NI 4060, NI 4065, and NI 4070/4071/4072 can exchange signals with NI and third-party switches during multipoint scanning operations. Two methods of scanning are available and are normally used: <u>synchronous</u> and <u>handshaking</u>.

Scanning is a method of sequentially connecting channels and is often used when connecting instrument(s) and device(s) under test (DUT), in a specific order.

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**Notes** For waveform acquisitions, the MC signal is generated after the entire waveform is acquired, not after each point.

SCXI switches require a controller, but PXI switches do *not* require a controller. The NI 4060, the NI 4065, and NI 4070/4071/4072 can act as controllers for SCXI switches. Refer to the *SCXI Communication* sections of <u>NI 4070/4071/4072</u>, <u>NI 4065</u>, and <u>NI 4060</u> for pin assignments and cable accessory information.

Refer to <u>Using Switches</u> for the theory of operation, scanning methods, and measurement considerations. Refer to <u>Triggering</u>, <u>Single Point</u> <u>Acquisitions</u>, and <u>Multiple Point Acquisitions</u> for programming flow information.

To determine if your switch supports scanning, and for switch configuration information and initial programming tips, refer to the *Scanning NI Switches with NI Digital Multimeters* section of the *NI Switches Help* (**Programming with NI-**

SWITCH»Features»Scanning»Scanning NI Switches with NI Digital Multimeters) at either of the following locations:

Condition	Path
If you have installed NI- SWITCH	Start»All Programs»National Instruments»NI- SWITCH»Documentation»NI Switches Help
If you have <i>not</i> installed NI- SWITCH	NI Product Manuals Library Web site

### **Scanning Options**

The following tables show the synchronization options for the National Instruments DMMs and switches.



**Notes** Refer to the <u>LabVIEW Trigger Routing</u> section or <u>Labwindows/CVI Trigger Routing</u> section for the software name associated with each hardware pin.

You can route the Measurement Complete (MC) signal to only one destination at a time, and you can receive the external trigger from only one source at a time.

A trigger and sample trigger connected to the AUX I/O connector *must* come from the *same* pin.

		NI PXI-4070/4071/4072	
Installation	Switch Type for Synchronization with DMM	Possible Destination of MC <sup>1</sup>	Poss
Any slot of a PXI chassis, and not controlling an SCXI chassis	PXI switch	<ul> <li>PXI Trigger Lines         <ol> <li>&lt;07&gt;</li> <li>AUX I/O Connector             Pin 6<sup>4</sup></li> </ol> </li> </ul>	•
	SCXI switch (installed in an SCXI chassis that is controlled by another device)	<ul> <li>AUX I/O Connector Pin 6<sup>4</sup></li> </ul>	•
Any slot of a PXI chassis,	PXI switch	<ul> <li>PXI Trigger Lines</li> <li>&lt;07&gt;</li> </ul>	•
and controlling an SCXI chassis using the AUX I/O	SCXI switch (installed in an SCXI chassis that is controlled by the NI PXI- 4070/4071/4072)	<ul> <li>AUX I/O Connector Pin 6<sup>3</sup></li> </ul>	•

Connector			
slot of a PXI/SCXI combination chassis, and	PXI switch	<ul> <li>PXI Trigger Lines</li> <li>&lt;07&gt;</li> <li>AUX I/O Connector Pin 6<sup>4</sup></li> </ul>	•
controlling the SCXI portion through the PXI backplane lines <sup>5</sup>	SCXI switch (installed in an SCXI chassis that is controlled by the NI PXI- 4070/4071/4072)	<ul> <li>Local Bus Right Line         <ol> <li>AUX I/O Connector</li> <li>Pin 6<sup>4</sup></li> </ol> </li> </ul>	•

<sup>1</sup> Refer to <u>SCXI Communication</u> and <u>Triggering</u> for the NI PXI-4070/4071/ I/O Connector.

<sup>2</sup> You can receive the Sample Trigger and the Trigger from the PXI Star L switch you are using to determine whether the switch can route a trigger t

<sup>3</sup> The AUX I/O Connector of the NI PXI-4070/4071/4072 can be used to c signal, and receive an external trigger.

<sup>4</sup> You can use a cable accessory for the AUX I/O Connector to connect th terminal block of the switch. Refer to <u>Triggering</u> for more information.

<sup>5</sup> Not all PXI-407x devices are capable of controlling the SCXI portion throe <u>Express Compatibility</u> for more information.

	NI PXI-4065	
Switch Type		Possi

Installation	for Synchronization with DMM	Possible Destination of MC <sup>1</sup>	
Any slot of a PXI chassis, and not controlling	PXI switch	<ul> <li>PXI Trigger Lines         <ol> <li>&lt;07&gt;</li> <li>AUX I/O Connector             Pin 6<sup>4</sup> </li> </ol></li></ul>	•
an SCXI chassis chassis chassis that is controlled by another device)	AUX I/O Connector     Pin 6 <sup>4</sup>	•	
Any slot of a PXI	PXI switch	PXI Trigger Lines     <07>	•
chassis, and controlling an SCXI chassis using the AUX I/O Connector	SCXI switch (installed in an SCXI chassis that is controlled by the NI PXI-4065)	• AUX I/O Connector Pin 6 <sup>3</sup>	•

<sup>1</sup> Refer to <u>SCXI Communication</u> and <u>Triggering</u> for the NI PXI-4065 for ca Connector.

<sup>2</sup> You can receive the Sample Trigger and the Trigger from the PXI Star L the switch you are using to determine whether the switch can route a trigg

<sup>3</sup> The AUX I/O Connector of the NI PXI-4065 can be used to control an S( receive an external trigger.

<sup>4</sup> You can use a cable accessory for the AUX I/O Connector to connect th terminal block of the switch. Refer to <u>Triggering</u> for more information.

NI F	PCI-4070 and NI PCI/PCIe-406	5
		Possił

Installation	Switch/Device Type for Synchronization with DMM	Possible Destination of MC <sup>1</sup>	for E Trig
Not controlling an SCXI chassis	Other devices	AUX I/O Connector     Pin 6 <sup>3</sup>	•
Controlling an SCXI chassis	SCXI switch	AUX I/O Connector Pin 6 <sup>2</sup>	•

<sup>1</sup> Refer to <u>SCXI Communication</u> and <u>Triggering</u> for the NI PCI-4070 for ca AUX I/O Connector. Refer to <u>SCXI Communication</u> and <u>Triggering</u> for the cable accessories for the AUX I/O Connector.

<sup>2</sup> The AUX I/O Connector of the NI PCI-4070 and NI PCI/PCIe-4065 can | SCXI chassis and to send and receive triggers.

<sup>3</sup> You can use a cable accessory for the AUX I/O Connector to connect th to the front terminal block of the switch. Refer to <u>Triggering</u> for the NI PCI the NI PCI/PCIe-4065 for more information.

NI USB-4065				
Installation	Switch/Device Type for Synchronization with DMM	Possible Destination of MC <sup>1</sup>	Possil for E Trig	
Not controlling an SCXI chassis	Other devices	<ul> <li>AUX I/O Connector Pin 6<sup>2</sup></li> </ul>	•	

<sup>1</sup> Refer to <u>SCXI Communication</u> and <u>Triggering</u> for the NI USB-4065 for cather AUX I/O Connector.

<sup>2</sup> You can use a cable accessory for the AUX I/O Connector to connect th to the front terminal block of the switch. Refer to <u>Triggering</u> for more inform

		NI PXI-4060	
Installation	Switch Type for Synchronization with DMM	Possible Destination of MC <sup>1</sup>	Pos
Any slot of a PXI chassis, and not	PXI switch	<ul> <li>PXI Trigger Lines &lt;06&gt;</li> <li>AUX I/O Connector Pin 6<sup>3</sup></li> </ul>	
controlling SCXI switch an SCXI (installed in an SCXI chassis chassis that is controlled by another device)	<ul> <li>AUX I/O Connector Pin 6<sup>3</sup></li> </ul>		
Any slot of	PXI switch	<ul> <li>PXI Trigger Lines &lt;06&gt;</li> </ul>	
a PXI chassis, and controlling an SCXI chassis using the AUX I/O Connector	SCXI switch (installed in an SCXI chassis that is controlled by the NI PXI-4060)	<ul> <li>AUX I/O Connector Pin 6<sup>2</sup></li> </ul>	
Right-most slot of a PXI/SCXI combination	PXI switch	<ul> <li>PXI Trigger Lines &lt;06&gt;</li> <li>AUX I/O Connector Pin 6<sup>3</sup></li> </ul>	

<sup>1</sup> Refer to <u>SC</u>	CXI Communicat	ion and T	riggering for th	e NI PXI-4060	for ca
<sup>2</sup> The AUX I/	O Connector of	the NI PX	-4060 can be	used to contro	l an S

<sup>3</sup> You can use a cable accessory for the AUX I/O Connector to connect th block of the switch. Refer to <u>Triggering</u> for more information.

		NI PCI-4060			
Installation	Switch/Device Type for Synchronization with DMM	Possible Destination of MC <sup>1</sup>	Possil for E Trig		
Not controlling an SCXI chassis	Other devices	<ul> <li>AUX I/O Connector Pin 6<sup>3</sup></li> </ul>	•		
Controlling an SCXI chassis	SCXI switch	AUX I/O Connector     Pin 6 <sup>2</sup>	•		

<sup>1</sup> Refer to <u>SCXI Communication</u> and <u>Triggering</u> for the NI PCI-4060 for ca AUX I/O Connector.

<sup>2</sup> The AUX I/O Connector of the NI PCI-4060 can be used to control an S the MC signal.

<sup>3</sup> You can use a cable accessory for the AUX I/O Connector to connect th to the front terminal block of the switch. Refer to <u>Triggering</u> for more inform

# LabWindows/CVI Trigger Routing

The following tables show which values are supported by National Instruments DMMs.

#### NIDMM\_ATTR\_MEAS\_COMPLETE\_DESTINATION

					Device
Destination	Description	PXI-	NI PCI- 4070		NI PCI/PCIe/US 4065
NIDMM_VAL_NONE (default)	No destination specified	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
NIDMM_VAL_EXTERNAL	Pin 6 on the AUX Connector	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
NIDMM_VAL_TTL0	PXI Trigger Line 0	$\checkmark$	_	$\checkmark$	—
NIDMM_VAL_TTL1	PXI Trigger Line 1	$\checkmark$		$\checkmark$	—
NIDMM_VAL_TTL2	PXI Trigger Line 2	$\checkmark$	_	$\checkmark$	—
NIDMM_VAL_TTL3	PXI Trigger Line 3	$\checkmark$	—	$\checkmark$	—
NIDMM_VAL_TTL4	PXI Trigger Line 4	$\checkmark$	—	$\checkmark$	—
NIDMM_VAL_TTL5	PXI Trigger Line 5	$\checkmark$	—	$\checkmark$	—
NIDMM_VAL_TTL6	PXI Trigger Line 6	$\checkmark$	—	$\checkmark$	—
NIDMM_VAL_TTL7	PXI Trigger Line 7	$\checkmark$		$\checkmark$	—
NIDMM_VAL_LBR_TRIG_0	Local Bus Right Trigger Line	$\sqrt{3}$	—	_	

0 of PXI/SCXI		
combination chassis		

# NIDMM\_ATTR\_TRIGGER\_SOURCE

Source	Description	NI PXI- 407x	
NIDMM_VAL_IMMEDIATE (default)	No trigger specified	$\checkmark$	$\checkmark$
NIDMM_VAL_EXTERNAL	Pin 9 on the AUX Connector	$\checkmark$	$\checkmark$
NIDMM_VAL_SOFTWARE_TRIG	Configures the DMM to wait until <u>niDMM_SendSoftwareTrigger</u> is called	$\checkmark$	√
NIDMM_VAL_TTL0	PXI Trigger Line 0	$\checkmark$	$\sqrt{2}$
NIDMM_VAL_TTL1	PXI Trigger Line 1	$\checkmark$	$\sqrt{2}$
NIDMM_VAL_TTL2	PXI Trigger Line 2	$\checkmark$	√ <sub>2</sub>
NIDMM_VAL_TTL3	PXI Trigger Line 3	$\checkmark$	
NIDMM_VAL_TTL4	PXI Trigger Line 4	$\checkmark$	
NIDMM_VAL_TTL5	PXI Trigger Line 5	$\checkmark$	
NIDMM_VAL_TTL6	PXI Trigger Line 6	$\checkmark$	
NIDMM_VAL_TTL7	PXI Trigger Line 7	$\checkmark$	
NIDMM_VAL_PXI_STAR	PXI STAR Trigger Line	$\checkmark$	
NIDMM_VAL_LBR_TRIG_1	Local Bus Right Trigger Line 1 of PXI/SCXI combination chassis	√ <sub>3</sub>	

$\checkmark$	

### NIDMM\_ATTR\_SAMPLE\_TRIGGER

Source	Description	NI PXI- 407x	NI PCI- 4070	
NIDMM_VAL_IMMEDIATE (default)	No trigger specified	$\checkmark$	$\checkmark$	$\checkmark$
NIDMM_VAL_EXTERNAL	Pin 9 on the AUX Connector	$\checkmark$	$\checkmark$	$\checkmark$
NIDMM_VAL_SOFTWARE	Configures the DMM to wait until <u>niDMM_SendSoftwareTrigger</u> is called		V	V
NIDMM_VAL_INTERVAL	Interval Trigger	$\checkmark$	$\checkmark$	$\checkmark$
NIDMM_VAL_TTL0	PXI Trigger Line 0	$\checkmark$	$\sqrt{2}$	$\checkmark$
NIDMM_VAL_TTL1	PXI Trigger Line 1	$\checkmark$	$\sqrt{2}$	$\checkmark$
NIDMM_VAL_TTL2	PXI Trigger Line 2	$\checkmark$	$\sqrt{2}$	$\checkmark$
NIDMM_VAL_TTL3	PXI Trigger Line 3	$\checkmark$	_	$\checkmark$
NIDMM_VAL_TTL4	PXI Trigger Line 4	$\checkmark$	—	$\checkmark$
NIDMM_VAL_TTL5	PXI Trigger Line 5	$\checkmark$	_	$\checkmark$
NIDMM_VAL_TTL6	PXI Trigger Line 6	$\checkmark$	_	$\checkmark$
NIDMM_VAL_TTL7	PXI Trigger Line 7	$\checkmark$	_	$\checkmark$
NIDMM_VAL_PXI_STAR	PXI STAR Trigger Line	$\checkmark$	_	$\checkmark$
NIDMM_VAL_LBR_TRIG_1	Local Bus Right Trigger Line 1 of PXI/SCXI combination chassis	√ <sub>3</sub>		
NIDMM_VAL_AUX_TRIG_1	Pin 3 on the AUX	$\checkmark$		$\checkmark$

<sup>1</sup> Specify TTL0 when the NI PXI-4060 is installed in the right-most slot of a combination chassis to generate MC on Local Bus Right Trigger Line 0 of the SCXI internal trigger lines.

<sup>2</sup> Lines TTL0, TTL1, and TTL2 refer to the device interconnect on the NI PCI-4070.

<sup>3</sup> Refer to the <u>chassis</u> section for more information regarding limitations of using this feature.

# LabVIEW Trigger Routing

The following tables show which values are supported by National Instruments DMMs.

#### **Measurement Complete Destination**

	Device							
Destination	Description	PXI-	NI PCI- 4070		NI PCI/PCIe/USB- 4065	NI PXI- 4060	NI PCI- 4060	F
NONE (default)	No destination specified	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	
EXTERNAL	Pin 6 on the AUX Connector	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	
TTLO	PXI Trigger Line 0	$\checkmark$	_	$\checkmark$	—	$\sqrt{1}$	—	
TTL1	PXI Trigger Line 1	$\checkmark$	—	$\checkmark$	—	$\checkmark$	—	
TTL2	PXI Trigger Line 2	$\checkmark$	—	$\checkmark$	—	$\checkmark$	—	
TTL3	PXI Trigger Line 3	$\checkmark$	—	$\checkmark$	—	$\checkmark$		
TTL4	PXI Trigger Line 4	$\checkmark$	—	$\checkmark$	—	$\checkmark$	—	
TTL5	PXI Trigger Line 5	$\checkmark$	_	$\checkmark$	—	$\checkmark$		
TTL6	PXI Trigger Line 6	$\checkmark$	—	$\checkmark$	—	$\checkmark$	-	
TTL7	PXI Trigger Line 7	$\checkmark$	_	$\checkmark$		_	_	
LBR TRIG 0	Local Bus Right Trigger Line	√ <sub>3</sub>		—		—	—	

0 of		
PXI/SCXI		
combination		
chassis		

# Trigger

	Device							
Source	Description	PXI-		NI PXI- 4065	NI PCI/PCIe/USB- 4065		NI PCI- 4060	
IMMEDIATE (default)	No trigger specified	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	
EXTERNAL	Pin 9 on the AUX Connector	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	√	$\checkmark$	
SOFTWARE	Configures the DMM to wait until <u>niDMM</u> <u>Send</u> <u>Software</u> <u>Trigger</u> is called	$\checkmark$	V	V	$\checkmark$	V	V	
TTL0	PXI Trigger Line 0	$\checkmark$	√ <sub>2</sub>	$\checkmark$	—	$\checkmark$	—	
TTL1	PXI Trigger Line 1	$\checkmark$	√ <sub>2</sub>	$\checkmark$	—	$\checkmark$	—	
TTL2	PXI Trigger Line 2	$\checkmark$	√ <sub>2</sub>	$\checkmark$	—	$\checkmark$	—	
TTL3	PXI Trigger Line 3	$\checkmark$		V		$\checkmark$	—	
TTL4	PXI Trigger Line 4	$\checkmark$		$\checkmark$	—	$\checkmark$	—	
TTL5	PXI Trigger	$\checkmark$		$\checkmark$	—	$\checkmark$		

	Line 5						
TTL6	PXI Trigger Line 6	$\checkmark$	—	$\checkmark$	—	$\checkmark$	—
TTL7	PXI Trigger Line 7	$\checkmark$	—	$\checkmark$	—	—	—
PXI STAR	PXI STAR Trigger Line	$\checkmark$	—	$\checkmark$	_	—	—
LBR TRIG 1	Local Bus Right Trigger Line 1 of PXI/SCXI combination chassis	√3					
AUX TRIG 1	Pin 3 on the AUX Connector	$\checkmark$		$\checkmark$	$\checkmark$		

# Sample Trigger

		Device						
Source	Description	PXI-	NI PCI- 4070		NI PCI/PCIe/USB- 4065	NI PXI- 4060	NI PCI- I 4060	
IMMEDIATE (default)	No trigger specified	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	
EXTERNAL	Pin 9 on the AUX Connector	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	
SOFTWARE TRIG	Configures the DMM to wait until <u>niDMM</u> <u>Send</u> <u>Software</u>	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	

	Trigger is called						
INTERVAL	Interval Trigger	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
TTLO	PXI Trigger Line 0	$\checkmark$	√ <sub>2</sub>	$\checkmark$		$\checkmark$	_
TTL1	PXI Trigger Line 1	$\checkmark$	√ <sub>2</sub>	$\checkmark$	—	$\checkmark$	—
TTL2	PXI Trigger Line 2	$\checkmark$	√ <sub>2</sub>	$\checkmark$	—	$\checkmark$	—
TTL3	PXI Trigger Line 3	$\checkmark$	—	$\checkmark$	—	$\checkmark$	—
TTL4	PXI Trigger Line 4	$\checkmark$	_	$\checkmark$		$\checkmark$	_
TTL5	PXI Trigger Line 5	$\checkmark$	—	$\checkmark$		$\checkmark$	_
TTL6	PXI Trigger Line 6	$\checkmark$		$\checkmark$	—	$\checkmark$	_
TTL7	PXI Trigger Line 7	$\checkmark$	—	$\checkmark$	—	—	—
PXI STAR	PXI STAR Trigger Line	$\checkmark$	—	$\checkmark$	—	—	—
LBR TRIG 1	Local Bus Right Trigger Line 1 of PXI/SCXI combination chassis	√3					
AUX TRIG 1	Pin 3 on the AUX Connector	$\checkmark$	—	$\checkmark$	$\checkmark$	—	—

<sup>1</sup> Specify TTL0 when the NI PXI-4060 is installed in the right-most slot of a combination chassis to generate MC on Local Bus Right Trigger Line 0 of the SCXI internal trigger lines.

<sup>2</sup> Lines TTL0, TTL1, and TTL2 refer to the device interconnect on the NI PCI-4070.

<sup>3</sup> Refer to the <u>chassis</u> section for more information regarding limitations of using this feature.

# **Acquiring Waveforms**

For the NI 4070/4071/4072 only, the following sections provide information about acquiring waveforms:

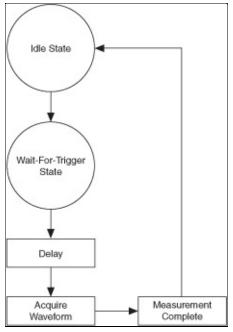
- Single Waveform Acquisitions
- <u>Multiple Waveform Acquisitions</u>
- <u>Synchronizing Waveform Measurements</u>
- <u>Acquiring High-Frequency Waveforms</u>



Note Continuous acquisitions cannot be performed using waveform mode.

For more information about optimizing waveform acquisitions, refer to Waveform Acquisitions.

# **Single Waveform Acquisitions**



For the NI 4070/4071/4072 only, configure a waveform acquisition by calling <u>niDMM Configure Waveform Acquisition</u>, which configures the DMM for a waveform acquisition by default. This function allows you to configure function, range, and resolution.

Initiate an acquisition by calling either <u>niDMM Initiate</u> or <u>niDMM Read</u> <u>Waveform</u>. In waveform acquisitions, you can configure the DMM to wait for a trigger before taking the first point sample. You can also specify a delay between when the DMM receives the trigger and when it acquires the first sample. Use <u>niDMM Configure Trigger</u> to set the **Trigger Source** and **Trigger Delay**. The **Trigger Delay** setting is Auto Delay (-1), which means the DMM waits an appropriate settling time before acquiring the waveform.

The latency of the NI 4070/4071/4072 is actually negative latency and can be reduced to zero or made positive by setting the <u>Trigger Delay</u> property appropriately.

Note The latency can be specified only within the tolerance indicated by the jitter specification for the input trigger. Refer to the <u>NI Product Manuals Library</u> Web site for the most recent specifications document for the NI 4070/4071/4072.

If you do not configure a trigger source, Immediate is used as the default

setting. Refer to <u>Scanning Switch Modules</u> for more information about possible trigger sources. To determine which values are supported by each device, refer to the <u>LabVIEW Trigger Routing</u> section.

After acquiring the entire waveform, the DMM can generate a <u>Measurement Complete</u> signal. The DMM then returns to the Idle State.



**Note** A single trigger initiates the entire waveform acquisition. Individual points cannot be triggered.

# **Multiple Waveform Acquisitions**

For the NI 4070/4071/4072 only, acquire multiple waveforms by calling <u>niDMM Initiate</u> and <u>niDMM Fetch Waveform</u> or <u>niDMM Read Waveform</u> for every waveform you capture.



**Note** Continuous acquisitions cannot be performed using waveform mode.

#### Synchronizing Waveform Measurements

For the NI 4070/4071/4072 only, when synchronizing multiple NI 407*x* devices, ensure that the measurement settling times and triggering are configured similarly. For example, if you enable Auto Zero on only one of the multiple NI 4070/4071/4072 devices or have different sampling rates, this increases the phase shift between the measured waveforms. Also, you must ensure that triggers are received from the same source on each NI 4070/4071/4072.

Power measurements are an example of an application in which synchronization of multiple NI 4070/4071/4072 devices is beneficial. One NI 4070/4071/4072 can acquire current while the other acquires voltage. Using the data collected from these two sources and Ohm's Law, you can determine the power. For an accurate representation of power, it is critical for these measurements to be synchronized.

To ensure that the two devices start the waveform acquisitions at the same time, you must configure the same external hardware trigger for each device. You should also set the settling time for each device to the same value. Normally, NI-DMM chooses the optimal settling time based on function and range parameters.

For example, to capture a voltage waveform in 300 V range and a current waveform in 1 A range, set the settling time for both measurements to 2 ms (this is the settling time required by the 300 V range and it is greater than 100 us required by 1 A range). The <u>default settling times</u> for voltage and current waveforms are different.

### **Acquiring High-Frequency Waveforms**

The NI 4050, NI 4065, and NI 4060 are not supported. When acquiring high-frequency waveforms, NI recommends calling <u>niDMM Initiate</u> before sending the trigger to initiate the signal. Calling <u>niDMM Initiate</u> early ensures that the DMM has finished settling and is ready to receive the trigger. If the trigger arrives while the DMM is still settling, the trigger is queued until the DMM is ready to respond. This delay can introduce skew into your data.

# **Configuring Measurement Timing**

If the resolution-based NI 4070/4071/4072 <u>measurement times</u> or NI 4065 <u>measurement times</u> selected by the driver are not acceptable for your application, you can set the aperture and/or settling times for the measurement directly using properties.

You can specify the aperture time in either seconds or powerline cycles. Set the <u>Aperture Time Units</u> property to the appropriate setting. If you choose powerline cycles as the unit, specify the <u>Powerline Frequency</u> using either <u>niDMM Configure Powerline Frequency</u> or the <u>Powerline</u> <u>Frequency</u> property. Set the <u>Aperture Time</u> property to the desired value. If the requested aperture time is less than the minimum required value, the driver uses the minimum value instead of the requested value.



**Notes** The NI 4050 is not supported.

You must set the <u>Aperture Time Units</u> property before setting the <u>Aperture Time</u> property.

To configure the settling time for a measurement or a waveform acquisition, set the <u>Settle Time</u> property. The settling time is specified in seconds. If the requested settling time is less than the minimum required value, the driver uses the minimum value instead of the requested value.

When the aperture time is explicitly set, the absolute resolution value is ignored. The effective resolution is determined by the chosen aperture. To reset the aperture or settling time, set these properties to Auto Selection (-1). Calling <u>niDMM Config Measurement</u> resets the aperture time to Auto. This allows the driver to program the hardware using the requested resolution.

When you set the aperture time directly, you may also want to set the Auto Zero, ADC calibration, and DC noise rejection values. These properties default to Auto Selection (-1). When the aperture is set, the driver disables Auto Zero and ADC Calibration and uses the Normal DC Noise Rejection setting. If you desire different values, set these properties to the desired setting. Reset the values to Auto Selection when you want the driver to choose the setting for these properties.



**Note** Aperture cannot be set directly for a waveform acquisition. Refer to <u>Sample Rate</u> for more information. To select the measurement time:

- LabVIEW
  - 1. Set the <u>Aperture Time Units</u> property in seconds or powerline cycles.
  - 2. Use the <u>Aperture Time</u> property.
- CVI/C++/Visual Basic
  - 1. Use <u>niDMM\_SetAttributeViInt32</u> to set the desired value for the <u>Aperture Time Units</u> attribute.
  - 2. Use the <u>niDMM\_SetAttributeViReal64</u> function to set the desired value for the <u>Aperture Time</u> attribute.

#### Averaging

During single or multipoint measurements with long aperture times, several shorter measurements can be taken with a new Auto Zero offset applied to each measurement to compensate for drift. To specify the <u>number of averages</u> in a measurement:

- LabVIEW
  - 1. Enable <u>Auto Zero</u>.
  - 2. Set the <u>Number Of Averages</u> property.
- CVI/C++/Visual Basic
  - 1. Enable <u>Auto Zero</u>.
  - 2. Use the <u>niDMM\_SetAttributeViReal64</u> function to set the desired value for the <u>NIDMM\_ATTR\_NUMBER\_OF\_AVERAGES</u> attribute.



**Note** When averaging resistance measurements, offset compensated ohms must be disabled.

# Examples

N

The following examples are instructional tools that demonstrate some of the functionality of the DMMs that you can use or integrate into your systems. These examples are available for the following ADEs:

- NI LabVIEW 7.1 or later
- LabWindows/CVI 7.0 or later
- Visual C/C++ 6.0 or later
- Visual Basic 6.0 or later

For examples of using NI DMMs with NI switch modules, refer to the <u>NI Developer Zone</u> Web site.

**Note** Not all examples are available for Visual C/C++ and Visual Basic.

### **Single Measurements**

These examples demonstrate how to take a specific type of measurement using the DMM. The default values for range and resolution are customized to the type of measurement. The following function calls are included in each example: <u>niDMM Initialize</u>, <u>niDMM Config Measurement</u>, <u>niDMM Read</u>, <u>niDMM Close</u>. Certain examples include additional function calls. For example, DC measurements sets the Powerline Frequency. AC measurements sets the AC Bandwidth.

#### Measure DC Voltage

This example acquires a single DC Voltage measurement. Specify the range and absolute resolution of the input signal and the powerline frequency of your system. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

#### Measure AC Voltage

This example acquires a single AC Voltage measurement. Specify the range, absolute resolution, and bandwidth of the input signal. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

#### **Measure DC Current**

This example acquires a single DC Current measurement. Specify the range and absolute resolution of the input signal and the powerline frequency of your system. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

#### **Measure AC Current**

This example acquires a single AC Current measurement. Specify the range, absolute resolution, and bandwidth of the input signal. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

#### Measure Resistance (2- or 4-wire; 4-wire: NI 4050 not supported.)

This example acquires a single resistance measurement. Set the measurement type to either a 2-wire or 4-wire resistance measurement. Specify the range and absolute resolution of the input signal and the

powerline frequency of your system. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

**Measure Frequency** (NI 4050, NI 4065, and NI 4060 are not supported.)

This example acquires a single frequency or period measurement. Specify the minimum expected measurement (in Hz or seconds) and the maximum amplitude of the input signal. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

#### **Diode Test**

This example acquires a single diode measurement. Specify the range and absolute resolution of the input signal and the powerline frequency of your system. The current source is configurable for NI 4065 and NI 4070/4071/4072 devices. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range. The NI 4050 and NI 4060 use a constant excitation (2 V at 100  $\mu$ A) for diode measurements. When using an NI 4050 and NI 4060, the configuration of the current source is ignored.

#### **DMM Measurement**

This example acquires a single measurement from an NI digital multimeter. Select the measurement function and range. Specify the resolution in digits of precision. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

#### Measure Capacitance (NI 4072 only)

This example acquires a single capacitance measurement. Specify the range of the input signal and the number of measurements to average. The measured value is displayed in the Measurement indicator. A Boolean indicator shows whether the measured value is out of range. The dissipation and quality factors are also displayed.

#### Measure Inductance (NI 4072 only)

This example acquires a single inductance measurement. Specify the range of the input signal and the number of measurements to average. The measured value is displayed in the Measurement indicator. A

Boolean indicator shows whether the measured value is out of range. The dissipation and quality factors are also displayed.

### **Multi Point Measurements**

These examples demonstrate how to use the <u>niDMM Configure Multi</u> <u>Point</u>. Only Immediate triggers are used.

#### Acq&Graph Multiple Samples

This example acquires multiple measurements. Select the measurement function, range, and absolute resolution. Specify the number of samples to acquire. <u>niDMM Read</u> is used to acquire the requested number of points. The data displays in a waveform graph.

#### **Cont Acq&Chart Multiple Samples**

This example performs a continuous acquisition. Select the measurement function, range, and absolute resolution. <u>niDMM Initiate</u> starts the acquisition. The requested samples are returned using <u>niDMM Fetch Multi Point</u> within the loop. The data displays in a waveform chart. The acquisition aborts when you click **Stop**.

# **Triggered Acquisitions**

These examples demonstrate the use of triggers during measurement acquisitions.

#### Acq One Sample-Ext Trig

This example acquires a single measurement when an external trigger is detected. Select the measurement function, range and absolute resolution. Specify the trigger source and a delay that elapses between the trigger and the measurement. The measured value displays in the Measurement indicator. A Boolean control indicates if the measured value is out of range.

#### Acq Multiple Samples-Ext Trig

This example acquires a finite number of measurements. The acquisition is initiated when a trigger is detected at the specified trigger source. All the points are acquired without a trigger. Select the measurement function, range, absolute resolution and power line frequency. Specify the trigger source and the number of samples to acquire. Read Multi Point is used to fetch the requested number of samples.

#### Acq Multiple Samples-Ext Sample Trig

This example acquires a finite number of measurements. The first measurement is acquired without a trigger, all remaining measurements are acquired when a trigger is detected at the Sample trigger source. Select the measurement function, range, absolute resolution and powerline frequency. Specify the sample trigger source and the number of samples to acquire. Read Multi Point is used to fetch the requested number of samples.

#### Cont Acq Multiple Samples-Ext Trig-Ext Sample Trig

This example acquires multiple measurements continuously. Every measurement is acquired when a trigger is detected at the Source according to the edge specified. Select the measurement function, range, absolute resolution and power line frequency. Specify the trigger/sample trigger source and the number of samples to acquire at a time. <u>niDMM Read Multi Point</u> is used to fetch the number of points available or the number of points requested (whichever is larger).

#### Cont Acq Multiple Samples-SW Sample Trig

This example performs a continuous acquisition. Each sample is triggered with a Software Trigger. Set the function, range, and resolution. Each time the Send Software Trigger function is called, Fetch retrieves the measurement and displays it in a waveform graph. The acquisition aborts when you click **Stop**.

#### Acq Multiple Samples-Interval Sample Trig

This example acquires multiple measurements continuously. The first measurement is acquired without a trigger. Each measurement thereafter is acquired when Send software trigger function is called. Select the measurement function, range, absolute resolution and power line frequency.

# **Advanced Examples**

These examples demonstrate some advanced features of the NI 4070/4071/4072.

#### Improve Stability with Auto Zero (LV, CVI only)

<u>Auto Zero</u> improves the stability of a measurement by removing internal DMM offsets. This example acquires a DC voltage or resistance measurement and returns the measured value to the user.

After specifying the instrument descriptor, select the function, range, and resolution. Enable and disable Auto Zero and observe the difference in the measurement.

#### Eliminate V offsets with OCO (LV, CVI only)

Offset Compensated Ohms allows you to measure resistances in the presence of offset voltages. Offset Compensated Ohms is useful for resistance measurements of 10 k $\Omega$  or less. This example acquires a 2-wire or 4-wire resistance measurement. After specifying the instrument descriptor, select the function, range, and resolution. Turning on Offset Compensated Ohms enables this feature.

#### Improve DC Resolution (LV, CVI only)

To remove low frequency noise from a measurement, set the <u>aperture</u> <u>time</u> to 1/f, where *f* is the noise frequency. Averaging multiple measurements together can further improve the resolution. This example acquires multiple DC voltage measurements. After specifying the instrument descriptor, select the function and range.

Input a stable, known voltage or short the input terminals (HI, LO). Specify 100 ms for the aperture time and set the number of averages to 8. Note the resolution available. Change the number of averages to 1 and observe the decrease in resolution.

Note Auto Zero must be enabled when averaging.

#### Improve DC Noise Rejection (LV, CVI only)

By varying the weighting of the samples that compose a single measurement, input noise can be attenuated. The <u>DC Noise Rejection</u> property controls the sample weighting. The signal frequencies removed from the measurement are related to the aperture time

selected.

This example acquires DC voltage measurements. The top graph in the VI displays the measurements. The second graph in the VI displays a plot of the theoretical noise rejection versus the frequency of the input signal.

- 1. Connect the supplied test leads to the input and drape the leads near a power cord.
- 2. After specifying the instrument descriptor, select the 100 mV range.
- 3. Select an aperture time of 10 ms.
- 4. Set DC Noise Rejection (DCNR) to Normal.
- 5. Note the displayed noise.
- 6. Repeat with an aperture time of 16.67 ms (for 60 Hz powerline) or 20 ms (for 50 Hz powerline).
- 7. Select a 100 ms aperture time and High Order DCNR.
- 8. Note the difference in displayed noise.

#### LC Cable Comp Load and Measure (NI 4072 only)

Cable compensation improves the accuracy of a capacitance or inductance measurement by removing the parasitic capacitance (open compensation) and parasitic inductance (short compensation) from the system. This example shows how to load compensation values from a file and pick the correct compensation value based on the current source frequency of the configured measurement.

### LC Cable Comp Measure and Save (NI 4072 only)

Cable compensation improves the accuracy of a capacitance or inductance measurement by removing the parasitic capacitance (open compensation) and parasitic inductance (short compensation) from the system. This example shows how to take compensation values for all possible current source frequencies and store them for later use and how to pick the correct compensation value based on the current source frequency of the configured measurement.

### LC Cable Compensation (NI 4072 only)

Cable compensation improves the accuracy of a capacitance or inductance measurement by removing the parasitic capacitance (open compensation) and parasitic inductance (short compensation) from the system. This example shows how to load or save compensation values from or to a file and pick the correct compensation value based on the current source frequency of the configured measurement.

## **Self-Calibration**

This example demonstrates how to perform a self-calibration and retrieve the calibration information from the NI 4070/4071/4072. Refer to the documentation for the recommended self-calibration interval. In this example the self-calibration operation is timed to show the speed at which this operation can be performed. The calibration information stores both the date and the temperature at which the DMM was last calibrated. This information can be used along with the current temperature of the device (which is often different than the ambient temperature of the system) to determine if a self-calibration should be performed. This example times the self-calibration and displays the results. <u>niDMM Self Cal</u> takes approximately 60 seconds.

## **Waveform Acquisitions**

These examples demonstrate the NI-DMM waveform acquisitions functions that enable you to use the NI 4070/4071/4072 as a high-voltage isolated digitizer.

#### Read & Graph Waveform (LV, CVI only)

This example acquires a waveform. Select the waveform acquisition function, range, sample rate, and number of points in the waveform. <u>niDMM Read Waveform</u> is used to acquire the requested waveform. The data is displayed in a waveform graph.

#### Fetch & Graph Waveform (LV, CVI only)

This example performs a waveform acquisition that employs several iterations of <u>niDMM Fetch Waveform</u>. Select the waveform acquisition function, range, sample rate, total number of points in the acquisition, and the number of samples to fetch at a time. The requested samples are returned using <u>niDMM Fetch Waveform</u> within the loop. The data retrieved in each iteration of the loop is displayed in a waveform graph. The acquisition is aborted when you press the **Stop** button.

#### Triggered Waveform (LV, CVI only)

This example performs a waveform acquisition that is started by a trigger. Select the waveform acquisition function, range, sample rate and number of points in the waveform. The requested samples are returned using <u>niDMM Fetch Waveform</u>. The data is displayed in a waveform graph.

#### Waveform Demo (LV only)

This demo acquires and displays the input waveform. Enter the Instrument Descriptor and click the **Run** button. While running, you can adjust the volts per division, and the timebase.

You can use Simulate Flag to use NI-DMM to simulate the NI 4070/4071/4072 waveform acquisition mode.

The timebase setting determines the acquisition rate of the instrument. The Acquisition rate indicator changes as you change the Timebase setting.

The subroutine of the example analyzes the acquired data to locate the first positive zero crossing of the signal. If the routine finds the zero

crossing, the example displays the waveform for (10)\*(Timebase seconds). If the analysis does not detect any positive zero crossings, the graph displays data from the start of the acquisition buffer.

This example and its block diagram source are available in the *Waveform Acquisition* folder of NI-DMM examples.

# **Performance Examples**

These examples demonstrate the DC Reading Rates Specifications for the NI 4070/4071/4072.

#### Achieving 7 Digits of Resolution (LV, CVI only)

This example demonstrates how to achieve 7 digits of resolution by averaging multiple samples together. Connect a short between the HI and LO terminals of the NI 4070/4071/4072. Specify the input descriptor of the device. Run the example. DC Voltage measurements are acquired on the selected range. The measured values are displayed in a graph. The Effective Digits of Resolution is calculated from the last 100 measurements and displayed in an indicator. The reading rate is also displayed. Click **STOP** to end the acquisition. You can change the aperture time, number of averages, and ADC Calibration settings. Run the VI to view the resulting Effective Digits of Resolution and Readings per Second for the specified configuration. Auto Zero must be set to **ON** when the number of averages is greater than 1.

#### Max DC Reading Rate at 7.5 Digits

This example demonstrates how to achieve the higher reading rate at 7½ digits of resolution with an NI 4071. Connect a short between the HI and LO terminals of the NI 4071. Specify the input descriptor of the device. Run the example. DC Voltage measurements are acquired on the selected range. The measured values are displayed on the front panel chart. The reading rate is displayed in an indicator. Click **STOP** to end the acquisition.

To achieve the higher reading rate of  $7\frac{1}{2}$ —digit resolution, the example configures the NI 4071 for  $7\frac{1}{2}$ —digit measurements, turns off ADC Calibration, and directly configures Auto Zero to **ON**, the Number of Averages to 4, and Aperture Time to 1 power-line cycle (PLC).

#### Maximizing DC Reading Rates (LV, CVI only)

This example demonstrates how to maximize DC reading rates for the NI 4070/4071/4072 by specifying the aperture time. Generally the DMM selects an aperture time to achieve a specified resolution, but in this example, you directly set the aperture time. The acquired measurements are then used to calculate the noise-free digits of

resolution.

Most traditional DMMs specify digits of resolution based on noise "counts" on a fixed display that defines the performance of the ADC. A more conservative approach is to calculate the effective resolution based on noise-free digits. You can use the example's calculation as a guide, in addition to the actual measured values, to determine the appropriate aperture time for a given measurement setup and conditions.

- 1. Connect a short or very stable input signal between the HI and LO terminals of the NI 4070/4071/4072.
- 2. Specify the instrument descriptor of the device.
- 3. Choose the desired function and range.
- 4. Use the Recommended Aperture Time Settings table to select an aperture time.
- 5. Run the example.
- 6. Click **STOP** to end the acquisition.

The measured value and reading rate are displayed in two indicators. The value for noise-free digits is based on the last 100 measurements and displayed in an indicator.

Use this example to find the speed-noise tradeoff that works best for your application. On the 10 V range with a shorted input, a 3.33 ms aperture time yields approximately 6½ digits of resolution at around 290 readings/s. Increasing the aperture time to 10 ms results in approximately 6.7 digits of resolution at around 100 readings/s.

By changing the aperture time to 100 ms, the resolution approaches 6.8 digits. This is the specified performance capability of the DMM before adding in other sources of noise (specified front-end noise on the most sensitive range, environmental noise, or noise from the device under test).

Try making resistance measurements with a 1 M $\Omega$  resistor and a 10 ms aperture time, but connect the resistor with the standard unshielded test leads included with the NI 4070/4071/4072. Powerline frequency noise in the environment most likely will interfere with this high impedance test setup. Because 10 ms is not a multiple of a line cycle (50 or 60 Hz), the DMM does not reject this environmental noise. This is evidenced by the value in the Noise-Free Resolution indicator.

Changing the aperture time to 16.66 ms (20 ms for 50 Hz line frequency outside the US) significantly improves the effective noise-free resolution. A 100 ms aperture time yields even better results.

# **NI-DMM LabVIEW Reference**

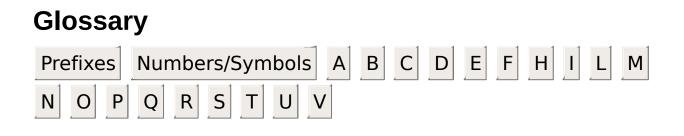
Expand this topic to view the VIs and properties included with NI-DMM that you can use to configure and operate your digital multimeter.

# **Operating System Support**

For information about the supported operating system (OS) for your device, refer to the <u>NI-DMM Readme File</u>.



**Note** Some devices are not supported under Windows Vista. Refer to your product <u>readme</u> for a complete list of products and their OS support.



# **Prefixes**

Prefix	Meaning	Value
f	femto	10-15
р	pico	10-12
n	nano	10 <sup>-9</sup>
μ	micro	10-6
m	milli	10-3
k	kilo	10 <sup>3</sup>
М	mega	106
G	giga	10 <sup>9</sup>
Т	tera	1012

# Numbers/Symbols

	-	
nV	nanovolts	10 <sup>-9</sup> volts
μV	microvolts	10 <sup>-6</sup> volts
μΩ	microohms	10 <sup>-6</sup> ohms
mV	millivolts	10 <sup>-3</sup> volts
mΩ	milliohms	10 <sup>-3</sup> ohms
MΩ	megaohms	10 <sup>6</sup> ohms
pА	picoamps	10 <sup>-12</sup> amperes
nA	nanoamps	10 <sup>-9</sup> amperes
μA	microamps	10 <sup>-6</sup> amperes
mA	milliamps	10 <sup>-3</sup> amperes

# Α

AC	alternating current
accuracy	How close a measurement is to the true or accepted value.
ADC	analog–to–digital converter
ADE	application development environment—a software environment incorporating the development, debug, and analysis tools for software development.
admittance	The reciprocal of impedance.
ammeter	An instrument that measures current.
aperture time	The period during which the ADC is reading the input signal.
ATE	automated test equipment—a term typically applied to computer-based systems for testing semiconductor components or circuit card assemblies.

burden	The voltage drop caused by current flowing through a
voltage	current measuring device.

# В

# С

calibration	The process of adjusting an instrument in order to guarantee its accuracy.
capacitance	The ability to hold an electrical charge.
CMRR	common-mode rejection ratioA measure of the capability of an instrument to reject a signal that is common to both input leads.
common- mode signal	The component of an input, common to the differential input.
crest factor CSM	The ratio of the peak value of a signal to its rms value. current shunt module

# D

- DC direct current
- DMM digital multimeter
- driver Software that controls a specific hardware device such as a DAQ device or GPIB interface device.
- DSP digital signal processor
- DUT device under test

# Ε

- ECMRR effective common-mode rejection ratioThe sum of the CMRR and of the NMRR at a given frequency. Also, the effective rejection of a given noise signal that is applied to both input leads as it is rejected first by the CMRR capability of the instrument, and then again by its NMRR capability. This specification is most useful at the power line frequency where most of the noise resides, and is only valid for DC measurements.
- EMF electromotive force
- ENOD effective number of digits
- EXTCLK External Clock signal.

F

frequency fThe basic unit of rate, measured in events or oscillations per second using a frequency counter or spectrum analyzer. Frequency is the reciprocal of the period of a signal.

# Н

handle	A unique variable you use to refer to a window or other interface element in C programming.
handshaking	A DMM/Switch protocol which makes it possible for two devices to synchronize operations.
HI	The high (or plus) voltage input for an instrument with isolated or balanced input. The other input is the LO input.
hysteresis	Lag between making a change and the effect of the change.
Hz	hertz

# I

I/O input/output

- impedance The measure of opposition to the flow of alternating currents.
- inductance The characteristic of a coil that generates a voltage due to changes in the current. An inductor creates a voltage that is the derivate of the current, while a capacitor creates a voltage that is the integral of the current.
- IVI interchangeable virtual instrument

## L

leakage Undesired radiation from the cable carrying a signal.

- LO lowThe low voltage (or minus) input of an instrument with a balanced or isolated input.
- loading The effect of connecting the output of one electronic device to the input of another, such as the connection of a unit under test to an instrument. The loading effect is the difference in the output value (for example, voltage) with and without the load. To prevent loading effects, the impedance of the load must be smaller than the output impedance of the source.

#### Μ

max maximum

- MC Measurement Complete—the signal emitted by a DMM after each measurement.
- min minutes or minimum

#### Ν

- NaN Not a Number—a digital display value for a floating-point representation of "Not a Number," as defined by the IEEE standard for binary floating point arithmetic; NaN is typically the result of an undefined operation, such as log(-1).
- NI 4050 Refers to the NI PCMCIA-4050.
- NI 4060 Refers to the NI PXI/PCI-4060.
- NI 4065 Refers to the NI PXI/PCI/PCIe/USB-4065.
- NI 4070 Refers to the NI PXI/PCI-4070.
- NI 4071 Refers to the NI PXI-4071.
- NI 4072 Refers to the NI PXI-4072.
- NI 407*x* Refers to the NI 4070, NI 4071, and NI 4072.
- NMRR normal-mode rejection ratioThe ability of the instrument to reject a normally (differentially) applied signal.
- noise Noise comes from both external sources, such as the AC powerline, motors, generators, transformers, fluorescent lights, soldering irons, CRT displays, computers, electrical storms, welders, and radio transmittersand internal sources, such as digital clocks, microprocessors, and switched mode power supplies. It corrupts signals you are trying to send or receive.
- normal- A signal applied differentially to the DMM front panel mode connectors for the purpose of measuring that signal. signal

0

offset The unwanted DC voltage due to amplifier offset voltages added to a signal.

#### Ρ

PCI A version of PCI that maintains the PCI software usage model and replaces the physical bus with a high-speed serial bus serving multiple lanes.

- period The period of a signal, most often measured from one zero crossing to the next zero crossing of the same slope. The period of a signal is the reciprocal of its frequency (in Hz). Period is designated by the symbol T.
- PLCs powerline cycles
- ppm parts per million
- precision The measure of the stability of an instrument and its capability to give the same measurement over and over again for the same input signal.

PXI Express A PXI module compatible with existing PXI slots and PXI hybrid slots. PXI Express compatible modules maintain hardware and software compatibility, with the exception of local bus.

# Q

quantization A process that converts continuous amplitude signals into one of a finite number of discrete amplitudes.

quantizer A device used in a quantization process.

### R

- resistance The resistance to the flow of electric current. One ohm ( $\Omega$ ) is the resistance through which one volt of electric force causes one ampere to flow.
- resolution The smallest amount of input signal change that an instrument or sensor can detect. Resolution is determined by the instrument noise (either circuit or quantization noise) and the smallest change that is detectable by the display system of the instrument.
- rms root mean square

### S

- scan list A list of connections/disconnections a switch module is programmed to make; typically used by switch modules.
- SCANADV Scanner advanced—a signal emitted by a switch module when the relays have been activated and are settled.
- sensitivity A measure of the smallest value of an input signal that an instrument can detect.

settling time The time required for an amplifier, relays, or other circuits to reach a stable mode of operation.

SFP Soft Front Panel

slew rate The voltage rate of change as a function of time. The maximum slew rate of an amplifier is often a key specification to its performance. Slew rate limitations are first seen as distortion at higher signal frequencies.

SSR solid–state relay

synchronous A DMM/Switch protocol in which the DMM takes a measurement and generates a digital pulsemeasurement complete (MC). When the switch receives the digital pulse, it advances to the next entry in its scan list.

### т

tempco temperature coefficient

thermal The voltage generated by the junction of dissimilar metals,

- voltages usually between connections, that increases as temperature increases.
- thermistor Semiconductor sensor that exhibits a repeatable change in electrical resistance as a function of temperature; most thermistors exhibit a negative temperature coefficient.

uncertainty The total calculated error caused by calibration error, noise, nonlinearity, offsets, temperature drift, and so on.

U

V	
V	volts
VI	Virtual Instrument—a program in the graphical programming language G; so called because it models the appearance and function of a physical instrument.
voltmeter	A usually direct-reading instrument used to measure voltage.
VXI	VME eXtensions for Instrumentation (bus)
VXI <i>plug&amp;play</i> SystemsAlliance	A group of VXI developers dedicated to making VXI devices as easy to use as possible, primarily by simplifying software development.

## **Important Information**

Warranty Copyright Trademarks Patents Warning Regarding Use of NI Products

## **Technical Support and Professional Services**

Visit the following sections of the National Instruments Web site at ni.com for technical support and professional services:

- <u>Support</u>—Online technical support resources at ni.com/support include the following:
  - Self-Help Resources—For answers and solutions, visit the award-winning National Instruments Web site for software drivers and updates, a searchable <u>KnowledgeBase</u>, product manuals, step-by-step troubleshooting wizards, thousands of example programs, tutorials, application notes, instrument drivers, and so on.
  - Free Technical Support—All registered users receive free Basic Service, which includes access to hundreds of Applications Engineers worldwide in the <u>NI Discussion</u> Forums at forums.ni.com. National Instruments Applications Engineers make sure every question receives an answer.

For information about other <u>technical support options</u> in your area, visit ni.com/services or <u>contact</u> your local office at ni.com/contact.

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- <u>System Integration</u>—If you have time constraints, limited inhouse technical resources, or other project challenges, National Instruments Alliance Partner members can help. To learn more, call your local NI office or visit ni.com/alliance.
- Declaration of Conformity (DoC)—A DoC is our claim of compliance with the Council of the European Communities using the manufacturers declaration of conformity. This system affords the user protection for electronic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting ni.com/certification.
- <u>Calibration Certificate</u>—If your product supports calibration, you

can obtain the calibration certificate for your product at ni.com/calibration.

If you searched ni.com and could not find the answers you need, contact your <u>local office</u> or NI corporate headquarters. You also can visit the <u>Worldwide Offices</u> section of ni.com/niglobal to access the branch office Web sites, which provide up-to-date contact information, support phone numbers, email addresses, and current events.

# Conventions

This help file uses the following conventions:

- < > 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.
  - This icon denotes a tip, which alerts you to advisory information.
- $\overline{\mathbb{N}}$

P

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 symbol is marked on a product, it denotes a component that may be hot. Touching this component may result in bodily injury.
- **bold** Bold text denotes items that you must select or click on in the software, such as menu items and dialog box options. Bold text also denotes parameter names, emphasis, an introduction to a key concept, a vector quantity, or a complex number.
- green Underlined text in this color denotes a link to a help topic, help file, or Web address.
- *italic* Italic text denotes variables or cross references. 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.

*monospace* Italic text in this font denotes text that is a placeholder for a *italic* word or value that you must supply.

# **Navigating Help (Windows Only)**

To navigate this help file, use the **Contents**, **Index**, and **Search** tabs to the left of this window or use the following toolbar buttons located above the tabs:

- **Hide**—Hides the navigation pane from view.
- Locate—Locates the currently displayed topic in the Contents tab, allowing you to view related topics.
- **Back**—Displays the previously viewed topic.
- Forward—Displays the topic you viewed before clicking the **Back** button.
- **Options**—Displays a list of commands and viewing options for the help file.

# **Searching Help (Windows Only)**

Use the **Search** tab to the left of this window to locate content in this help file. If you want to search for words in a certain order, such as "related documentation," add quotation marks around the search words as shown in the example. Searching for terms on the **Search** tab allows you to quickly locate specific information and information in topics that are not included on the **Contents** tab.

#### Wildcards

You also can search using asterisk (\*) or question mark (?) wildcards. Use the asterisk wildcard to return topics that contain a certain string. For example, a search for "prog\*" lists topics that contain the words "program," "programmatically," "progress," and so on.

Use the question mark wildcard as a substitute for a single character in a search term. For example, "?ext" lists topics that contain the words "next," "text," and so on.



**Note** Wildcard searching will not work on Simplified Chinese, Traditional Chinese, Japanese, and Korean systems.

#### **Nested Expressions**

Use nested expressions to combine searches to further refine a search. You can use Boolean expressions and wildcards in a nested expression. For example, "example AND (program OR VI)" lists topics that contain "example program" or "example VI." You cannot nest expressions more than five levels.

#### **Boolean Expressions**

Click the **•** button to add Boolean expressions to a search. The following Boolean operators are available:

- **AND** (default)—Returns topics that contain both search terms. You do not need to specify this operator unless you are using nested expressions.
- **OR**—Returns topics that contain either the first or second term.
- **NOT**—Returns topics that contain the first term without the second term.
- **NEAR**—Returns topics that contain both terms within eight words of each other.

#### **Search Options**

Use the following checkboxes on the **Search** tab to customize a search:

- **Search previous results**—Narrows the results from a search that returned too many topics. You must remove the checkmark from this checkbox to search all topics.
- Match similar words—Broadens a search to return topics that contain words similar to the search terms. For example, a search for "program" lists topics that include the words "programs," "programming," and so on.
- Search titles only—Searches only in the titles of topics.

# **Printing Help File Topics (Windows Only)**

Complete the following steps to print an entire book from the **Contents** tab:

- 1. Right-click the book.
- 2. Select **Print** from the shortcut menu to display the **Print Topics** dialog box.
- 3. Select the **Print the selected heading and all subtopics** option.
  - Note Select Print the selected topic if you want to print the single topic you have selected in the **Contents** tab.
- 4. Click the **OK** button.

#### **Printing PDF Documents**

This help file may contain links to PDF documents. To print PDF documents, click the print button located on the Adobe Acrobat Viewer toolbar.

## NI 4050

The NI 4050 is a 5½ digit DMM for the PCMCIA bus. For more detailed information about the NI 4050 specifications, refer to <u>Related</u> <u>Documentation</u> for the NI 4050 specifications document.

#### **Front Panel Connections**

The NI 4050 connects to an accessory cable that connects the DMM to a pair of test probes with shrouded banana plugs, which are included with your DMM. Refer to <u>Related Documentation</u> for the *NI Digital Multimeters Getting Started Guide* for more information on connecting the NI 4050 to the test probes. For an illustration of the front panel connectors and wiring instructions, refer to <u>NI PCMCIA-4050 Front Panel Connections</u>.

#### Operation

The following table lists the functions and ranges supported by the NI 4050:

Function	Ranges	
DC Voltage	20 mV, 200 mV, 2 V, 25 V, 250 V	
AC Voltage	20 mV, 200 mV, 2 V, 25 V, 250 V	
DC Current*	20 mA, 200 mA	
AC Current*	20 mA, 200 mA	
2-Wire Resistance	200 Ω, 2 kΩ, 20 kΩ, 200 kΩ, 2 MΩ, 20 MΩ	
Diode	2 V at 100 μA	
* You must use a current shunt module (CSM) to measure current on the NI 4050. For more information, refer to <u>Measuring Current</u> and to <u>Related Documentation</u> for the <i>NI Digital Multimeters Getting Started Guide</i> .		

#### Calibrating the NI 4050

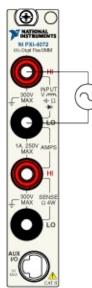
Calibration maximizes the accuracy of a DMM. To ensure accuracy, you must perform calibration. NI recommends you calibrate annually.

For information on calibrating the NI 4050 using National Instruments Calibration Executive, refer to the <u>NI Calibration Solutions</u> Web site.

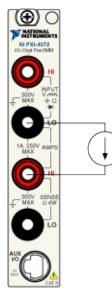
## **Waveform Acquisition Fundamentals**

In addition to its DMM capabilities, the NI 4070 can acquire waveforms. To properly configure the NI 4070 for acquiring waveforms, you should be familiar with <u>measurement quality</u> and the <u>Nyquist theorem</u> and how it affects <u>analog bandwidth</u> and the <u>sample rate</u>. You should also be familiar with <u>digitizer resolution</u>.

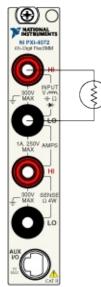
## **Voltage Waveform**



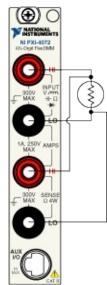
## **Current Waveform**



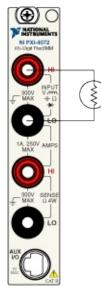
# **Temperature (2-wire RTD)**



# **Temperature (4-wire RTD)**

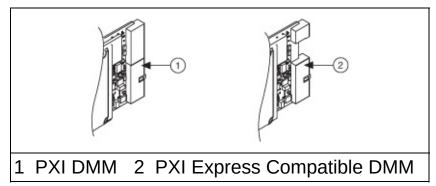


# **Temperature (Thermistor)**



# **PXI Express Compatibility**

The PXI Systems Alliance (pxisa.org) recently defined a modification for PXI modules. Modified PXI modules provide future compatibility for systems incorporating PCI Express signaling in PXI. Previous versions of these modules had two large PXI connectors. In the modified PXI Express compatible DMM, the top connector has been replaced with a smaller connector. You may notice a series of regularly spaced holes in the printed circuit board that are not used by the smaller connector.



Modified PXI modules are supported by new hybrid PXI chassis slots that can accept either future PXI Express modules or existing modified PXI modules. To provide future compatibility, modified modules do not include the pins used to implement 64-bit PCI and local bus. NI PXI modules do not implement 64-bit PCI. The following functionality is preserved in the smaller top connector:

- All PXI chassis accept modified PXI modules.
- Product specifications are the same.
- No software changes (application or driver software) are required.
- Modified PXI modules are compatible with existing PXI timing and PXI triggering capabilities.
- The speed and capability of all PXI communication is unchanged.

PXI Express compatible DMMs do not support SCXI control and triggering via the backplane of a PXI/SCXI combination chassis.

PXI Express compatible DMMs are capable of SCXI control and triggering in an NI PXI-1010/1050 chassis using external cabling with an NI SCXI-1357/1358/1359 communication backplane. PXI Express compatible DMMs are not capable of controlling SCXI in an NI PXI- 1011/1052 chassis. You can still accomplish SCXI triggering when using the NI PXI-1011/1052 chassis by cabling from the DMM to the SCXI module front panel.

For more information on SCXI control and triggering using a PXI/SCXI combination chassis, reference KnowledgeBase entry 3V07KP2W. Refer to ni.com/support to access the KnowledgeBase.

# **Error and Warning Codes**

Decimal Value	Hexadecimal Value	Error or Warning
-1074126845	BFFA2003	NIDMM_ERROR_MAX_TIME_EXCI
-1074118656	BFFA4000	NIDMM_ERROR_UNKNOWN_DEV
-1074118655	BFFA4001	NIDMM_ERROR_INVALID_DESCRI
-1074118654	BFFA4002	NIDMM_ERROR_INVALID_DRIVEF
-1074118653	BFFA4003	NIDMM_ERROR_ATTRIBUTE_INV
-1074118652	BFFA4004	NIDMM_ERROR_INVALID_TRIG
-1074118651	BFFA4005	NIDMM_ERROR_TRANSFER_IN_PI
-1074118650	BFFA4006	NIDMM_ERROR_INTERNAL
-1074118649	BFFA4007	NIDMM_ERROR_NUM_SESSIONS_
-1074118648	BFFA4008	NIDMM_ERROR_REV_QUERY_FAI

-1074118647	BFFA4009	NIDMM_ERROR_AC_TEST_FAILUF
-1074118646	BFFA400A	NIDMM_ERROR_DC_TEST_FAILUF
-1074118645	BFFA400B	NIDMM_ERROR_RESISTANCE_TES
-1074118644	BFFA400C	NIDMM_ERROR_INVALID_SCAN_(
-1074118643	BFFA400D	NIDMM_ERROR_INVALID_AUTO_I
-1074118642	BFFA400E	NIDMM_ERROR_INVALID_RESOLU
-1074118641	BFFA400F	NIDMM_ERROR_DATA_NOT_AVAI
-1074118640	BFFA4010	NIDMM_ERROR_SELF_CAL_OVER
-1074118639	BFFA4011	NIDMM_ERROR_DEVICE_IN_USE_
-1074118638	BFFA4012	NIDMM_ERROR_EXT_TRIG_LINE_
-1074118637	BFFA4013	NIDMM_ERROR_CALIBRATION
-1074118636	BFFA4014	NIDMM_ERROR_DRIVER_INITIAL

-1074118634 B -1074118633 B -1074118632 B	3FFA4015 3FFA4016 3FFA4017 3FFA4018	
-1074118633 B -1074118632 B	3FFA4017	NIDMM_ERROR_SELF_TEST_FAIl
–1074118632 B		NIDMM_ERROR_SELF_TEST_FAIl
		NIDMM_ERROR_WAVEFORM_CO
	3FFA4019	NIDMM_ERROR_WAVEFORM_AC
–1074118630 B	BFFA401A	NIDMM_ERROR_INVALID_MEAS

-1074118144	BFFA4200	NIDMM_ERROR_EXTCAL_INV
-1074118143	BFFA4201	NIDMM_ERROR_EXTCAL_INC
-1074118142	BFFA4202	NIDMM_ERROR_EXTCAL_CAL
-1074118141	BFFA4203	NIDMM_ERROR_EXTCAL_SIM
-1074118140	BFFA4204	NIDMM_ERROR_EXTCAL_RES
–1074118138	BFFA4206	NIDMM_ERROR_EXTCAL_SES
-1074118137	BFFA4207	NIDMM_ERROR_EXTCAL_IMP
–1074118136	BFFA4208	NIDMM_ERROR_EXTCAL_IMP
-1074118135	BFFA4209	NIDMM_ERROR_EXTCAL_BAD
-1074118134	BFFA420A	NIDMM_ERROR_EXTCAL_DEP
–1074118133	BFFA420B	NIDMM_ERROR_EXTCAL_BAD
-1074117856	BFFA4320	NIDMM_ERROR_FIRMWARE_L

-1074117855	BFFA4321	NIDMM_ERROR_DRIVER_TIMEOU
-1074117854	BFFA4322	NIDMM_ERROR_ACQ_IN_PROGRE
–1074117853	BFFA4323	NIDMM_ERROR_VERSION_MISMA
-1074117852	BFFA4324	NIDMM_ERROR_EEPROM_NOT_RI
-1074117851	BFFA4325	NIDMM_ERROR_SET_SA_SOURCE
-1074117850	BFFA4326	NIDMM_ERROR_SCANLIST_SIZE_
-1074117849	BFFA4327	NIDMM_ERROR_FEATURE_NOT_S
-1074117848	BFFA4328	NIDMM_ERROR_BAD_READ
-1074117847	BFFA4329	NIDMM_ERROR_AZ_REQUIRED
-1074117846	BFFA432A	NIDMM_ERROR_MAX_SETTLE_TI
-1074117756	BFFA4384	NIDMM_ERROR_INTERNAL_HARI
-1074117755	BFFA4385	NIDMM_ERROR_EEPROM_WRITE
-1074117754	BFFA4386	NIDMM_ERROR_SERIAL_PORT_RE

-1074117753	BFFA4387	NIDMM_ERROR_DEVICE_NOT_RE
-1074117752	BFFA4388	NIDMM_ERROR_HARDWARE_FIF(
-1074117751	BFFA4389	NIDMM_ERROR_HARDWARE_STA
-1074117750	BFFA4390	NIDMM_ERROR_CABLE_COMP_N
-1074117749	BFFA4391	NIDMM_ERROR_INVALID_CABLE_
1073364993	3FFA4001	NIDMM_WARN_SIMULATING
1073365504	3FFA4200	NIDMM_WARN_EXTCAL_SELF_CA
1073365505	3FFA4201	NIDMM_WARN_EXTCAL_BUFFER_
1073368960	3FFA4F80	NIDMM_WARN_UNDERRANGE

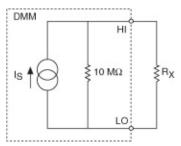
## Measuring on the 100 $M\Omega$ Range

The 100 M $\Omega$  range provides a unique capability, allowing measurements up to 1.05 G $\Omega$  (NI 4065 and NI 4070/4072) or 5 G $\Omega$  (NI 4071), because of the methodology of the measurement and the high–impedance design of the NI 4065 and NI 4070/4071/4072. This range allows 2-wire operation only, and Offset Compensated Ohms cannot be enabled.

It is difficult to get a meaningful measurement with resistances above 10  $M\Omega$  without good shielding—including shielding of the resistor under test. Enclose the resistor under test in a metallic box, and connect this enclosure to LO terminal. In the laboratory, even a small box covered with a single, continuous sheet of aluminum foil helps significantly with this kind of measurement.

#### Noise

The following diagram shows an equivalent circuit for all measurements above the 10  $\ensuremath{\text{M}\Omega}$  range.



The voltage across the resistor is measured by the NI 4056 and NI 4070/4071/4072 and the resistor is calculated from:

$$R_{x} = V / (I_{s} - (V/10 \text{ M}\Omega))$$

where

 $R_x$  = the resistor under test (up to 1.05 G $\Omega$  on the NI 4065 and NI 4070/4072, or up to 5 G $\Omega$  on the NI 4071)

V = the voltage measured by the DMM with Rx applied

 $I_{\rm s}$  = the source current (nominally 0.95 uA)

For 100 M $\Omega$  to 1 G $\Omega$  (NI 4065 and NI 4070/4072) or for 100 M $\Omega$  to 5 G $\Omega$  (NI 4071), consider the following:

• The ADC only uses 10% of its range. Typical accuracy values are in the 5% range.

• Any environmental noise or interference is amplified as the resistance being measured is increased. The requirement for good shielding increases as the resistor value increases.

The Johnson noise of the resistor is always a factor in the measurement. Calculating from the equation described in <u>Noise</u>, the Johnson noise of typical high M $\Omega$  resistors is listed below in ppm of reading, assuming a bandwidth of 10 Hz (roughly equivalent to a 100 ms aperture time)

Measurements above 10 M $\Omega$  should be made with as long an <u>aperture</u> time as possible, and 100 ms is the minimum recommended value. <u>Highorder DC noise rejection</u> is recommended.

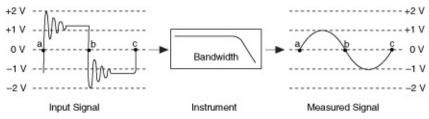
Resistor Value	Johnson Noise <sup>1</sup> (V <sub>p–p</sub> ) (10 Hz bandwidth at 23 °C)	
10 ΜΩ	8 μV	
30 MΩ	15 μV	
100 MΩ	27 μV	
300 MΩ	46 μV	
1 GΩ	85 μV	
5 GΩ	189 μV	
<sup>1</sup> Represents the "ideal" noise due to the Johnson noise of the resistor. Actual noise may be higher, due to environment, poor shielding, and so		

Johnson Noise of Various High–Value Resistors

on.

## **Analog Bandwidth**

Analog bandwidth describes the frequency range (in Hz) in which a signal can be acquired accurately. This limitation is determined by the inherent frequency response of the input path, which causes loss of amplitude and phase information. Analog bandwidth is the frequency at which the measured amplitude is 3 dB below the actual amplitude of the signal. This amplitude loss occurs at very low frequencies if the signal is AC coupled and at very high frequencies regardless of coupling. When the signal is DC coupled, the bandwidth of the amplifier extends all the way to the DC voltage. The following figure illustrates the effect of analog bandwidth on a high-frequency signal.



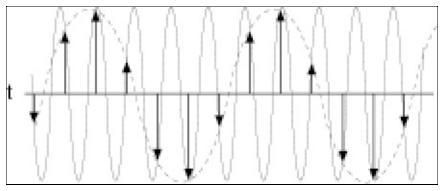
As indicated in the specifications, the NI 4070/4071/4072 has a voltage measurement bandwidth of 300 kHz. This specification means that only signals ≤300 kHz can be accurately acquired. Note that this number is different than the maximum sampling rate of the NI 4070/4071/4072 (1.8 MS/s). The Nyquist Theorem implies that the maximum signal frequency that can be effectively acquired is 900 kHz. However, the bandwidth actually limits the maximum frequency to 300 kHz. Refer to sample rate for more information.

### **Bandwidth Considerations**

The resistance and the capacitance present in the signal path can affect high frequency signals. The larger the capacitance and the resistance, the lower the bandwidth of the signal path. The NI 4070/4071/4072 input capacitance can be found in the specification. Note that additional capacitance can be introduced in the cabling that is used, and any other front-end accessories such as switches. This capacitance not only impacts the performance of the waveform acquisition, but can also impact the source of the signal by loading it. Having a low-impedance source and minimal added capacitance is best for optimal operation when acquiring high frequency signals. Use short cable lengths of a lowcapacitance, low resistance, and low dielectric absorption for best results.

## **Nyquist Theorem**

The Nyquist theorem states that a signal must be sampled at least twice as fast as the bandwidth of the signal; otherwise, aliased products in the band of interest can distort the signal, causing loss of information. An alias is a false lower frequency component that appears in sampled data acquired at too low a sampling rate. The following figure shows an 800 kHz sine wave digitized by a 1 MS/s ADC. The dotted line indicates the aliased signal recorded by the ADC at that sample rate.

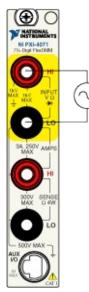


The 800 kHz frequency aliases back in the passband, falsely appearing as a 200 kHz sine wave. To prevent aliasing in the passband, a lowpass filter limits the frequency content of the input signal above the Nyquist rate. The <u>analog bandwidth</u> of the NI 4070/4071/4072 is 300 kHz and you can avoid aliased signals in that passband by sampling at the full rate of 1.8 MS/s.

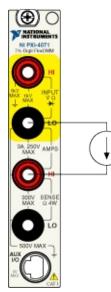
## **Input Coupling**

The input channels can be configured for DC coupling or AC coupling. DC coupling allows DC and low-frequency components of a signal to pass through without attenuation. In contrast, AC coupling removes DC offsets and attenuates low frequency components of a signal. Use AC coupling to zoom in on AC signals with large DC offsets, such as switching noise on a 12 V power supply. Refer to the specifications for input limits that must be observed regardless of coupling.

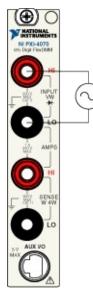
# **Voltage Waveform**



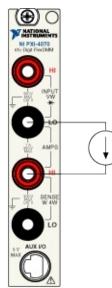
# **Current Waveform**



# Voltage Waveform



# **Current Waveform**



# **Front Panel Connections**

Move the mouse over the text to view the wiring diagrams for the NI 4050, and click for additional information.

DC Voltage

AC Voltage

DC Current

AC Current

2-Wire Resistance

Voltage Drop Across a Diode

## Using NI-DMM in LabVIEW

This topic assumes that you are using the National Instruments LabVIEW ADE to manage your code development and that you are familiar with the ADE.

To develop an NI-DMM application in LabVIEW, follow these general steps:

- 1. Open an existing or new LabVIEW VI.
- 2. From the Function Palette (the default location), locate the NI-DMM VIs at **All Functions»NI Measurements»NI-DMM**.
- 3. Select the VIs that you want to use and drop them on the block diagram to build your application.

#### **Example Programs**

LabVIEW users can use the LabVIEW Example Finder to search or browse examples. NI-DMM examples are classified by keyword, so you can search for a particular device or measurement function.

To browse the NI-DMM examples available in LabVIEW, launch LabVIEW, click **Find Examples**, and navigate to **Hardware Input and Output»Modular Instruments»NI-DMM (Digital Multimeters)**.

You can find the installed locations of example programs in the <u>NI-DMM</u> <u>Readme File</u>. For additional information regarding NI-DMM examples, refer to <u>Examples</u>.

## Using NI-DMM in LabWindows/CVI

This topic assumes that you are using the LabWindows™/CVI™ ADE to manage your code development and that you are familiar with the ADE.

To develop an NI-DMM application in LabWindows/CVI, follow these general steps:

- 1. Open an existing or new project file.
- 2. Load the NI-DMM function panel. You can find the installed location of the NI-DMM function panel in the <u>NI-DMM Readme</u><u>File</u>.
- 3. Use the function panel to navigate the function hierarchy and generate function calls with the proper syntax and variable values.

#### **Example Programs**

LabWindows/CVI users can use the NI Example Finder to search or browse examples. NI-DMM examples are classified by keyword, so you can search for a particular device or measurement function. To browse the NI-DMM examples available in LabWindows/CVI, launch LabWindows/CVI, select Help»Find Examples, and navigate to Hardware Input and Output»Modular Instruments»NI-DMM (Digital Multimeters).

You can find the installed locations of example programs in the <u>NI-DMM</u> <u>Readme File</u>. For additional information regarding NI-DMM examples, refer to <u>Examples</u>.

## Using NI-DMM in Visual C++

This topic assumes that you are using the Microsoft Visual C++ ADE to manage your code development and that you are familiar with the ADE.

To develop an NI-DMM application in Visual C++, follow these general steps:

- 1. Open an existing or new Visual C++ project.
- Create source files of type .c (C source code) or .cpp (C++ source code) and add them to the project. Make sure that you include the NI-DMM header file, nidmm.h, as follows in your source code files: #include "nidmm.h"
- Specify the directory that contains the NI-DMM header file under the Preprocessor»Additional include directories settings in your compiler—for Visual C++ 6.0 these files are under Project»Settings»C/C++. You can find the installed location of the NI-DMM header files in the <u>NI-DMM Readme File</u>.
- 4. Add the NI-DMM import library nidmm.lib to the project under **Link»General»Object/Library Modules**. You can find the installed location of the NI-DMM import library files in the <u>NI-DMM</u> <u>Readme File</u>.
- 5. Add NI-DMM function calls to your application.
- 6. Build your application.

### Example Programs

You can find the installed locations of example programs in the <u>NI-DMM</u> <u>Readme File</u>. For additional information regarding NI-DMM examples, refer to <u>Examples</u>.

### **String Passing**

To pass strings, pass a pointer to the first element of the character array. Be sure that the string is null-terminated.

### **Parameter Passing**

By default, C passes parameters by value. Remember to pass pointers to variables when you need to pass by address.

## Using NI-DMM in Visual Basic

This topic assumes that you are using the Microsoft Visual Basic ADE to manage your code development and that you are familiar with the ADE.

To develop an NI-DMM application in Visual Basic, follow these general steps:

- 1. Open an existing or new Visual Basic project.
- 2. Create files necessary for your application: .frm (form definition and event handling code), .bas (Visual Basic generic code module), or .cls (Visual Basic class module) and add them to the project.
- 3. Add a reference to the National Instruments DMM Library (NIDMM), which is part of the NI-DMM DLL. In Visual Basic 6.0, select the **Project**»**References** menu option and National Instruments DMM Library (NIDMM). If you do not see the NIDMM listed there, click **Browse** and locate nidmm\_32.dll. You can find the installed location of the NI-DMM DLL in the <u>NI-DMM Readme File</u>.
- 4. Use the Object Browser <F2> to find function prototypes and constants.
- 5. Add NI-DMM function calls to your application.
- 6. Run your application by clicking **Run**.

#### **Example Programs**

You can find the installed locations of example programs in the <u>NI-DMM</u> <u>Readme File</u>. For additional information regarding NI-DMM examples, refer to <u>Examples</u>.

To load an example project with Visual Basic 6.0 or later, select **File»Open Project**, then select the .vbp file of your choice.

### String Passing

In Visual Basic, variables of data type String do not need special modifications to be passed to NI-DMM functions. Visual Basic automatically appends a null character to the end of a string before passing it (by reference, because strings cannot be passed by value in Visual Basic) to a procedure or function.

#### **Parameter Passing**

By default, Visual Basic passes parameters by reference. Prepend the ByVal keyword if you need to pass by value.

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