Modular Instruments—Digital Multimeter (DMM) Course Exercises

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Contents

Student Guide

Thank you for purchasing the Modular Instruments—Digital Multimeter (DMM) course kit. This kit contains the materials used in the 4-hour online course.

You can apply the full purchase price of this course kit toward the corresponding course registration fee if you register within 90 days of purchasing the kit. Visit `ni.com/training` to register for a course and to access course schedules, syllabi, and training center location information.

A. Course Description

The Modular Instruments—Digital Multimeter course teaches you digital multimeter fundamentals, including theory and use. This course also prepares you to set up the hardware, configure the device, and program your application using NI LabVIEW software. In addition, the course introduces you to NI switches to help you extend the functionality of your application.

This course assumes that you have taken the LabVIEW Core 1 course or have equivalent knowledge, have familiarity with benchtop or handheld DMMs, and have knowledge of basic circuit theory.

In the exercise manual, each lesson consists of a set of exercises to reinforce topics.

B. What You Need to Get Started

Course Materials

Before you use this manual, make sure you have the following items:

- ❑ Windows XP or later installed on your computer
- ❑ LabVIEW Full or Professional Development System 2011 or later
- ❑ NI-DMM
- ❑ NI-Switch
- ❑ NI-DAQmx
- ❑ PXI-4070 and test probes
- ❑ PXI-2503
- ❑ TB-2605

❑ PXI controller

❑ PXI chassis

C. Course Goals

This course presents the following topics:

- Configuring and operating your DMM
- Understanding DMM specifications
- Setting up signal connections to the hardware
- Using LabVIEW to program DMM applications
- Using the functions on the NI-DMM palette
- Understanding the DMM measurement cycle
- Understanding advanced DMM specifications (Auto-Range, ADC Cal, Auto-Zero)

D. Course Conventions

The following conventions are used in this manual:

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

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

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

italic — Italic text denotes variables, emphasis, a cross-reference, or an introduction to a key concept. Italic text 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 enter from the keyboard, sections of code, programming examples, and syntax examples. This font also is used for the proper names of disk drives, paths, directories, programs, subprograms, subroutines, device names, functions, operations, variables, filenames, and extensions.

3

Using the DMM

Exercise 3-1 Using the NI-DMM Soft Front Panel

Objective: Measure resistance by using the NI-DMM Soft Front Panel

1. Open the NI-DMM Soft Front Panel by selecting **Start»All Programs» National Instruments»NI-DMM»DMM Soft Front Panel**.

2. DMM probes have already been connected to the Input HI and Input LO terminals of the NI PXI-4070 DMM. The pins of the DMM probes are connected to a 10 kΩ resistor as shown in Figure 3-1.

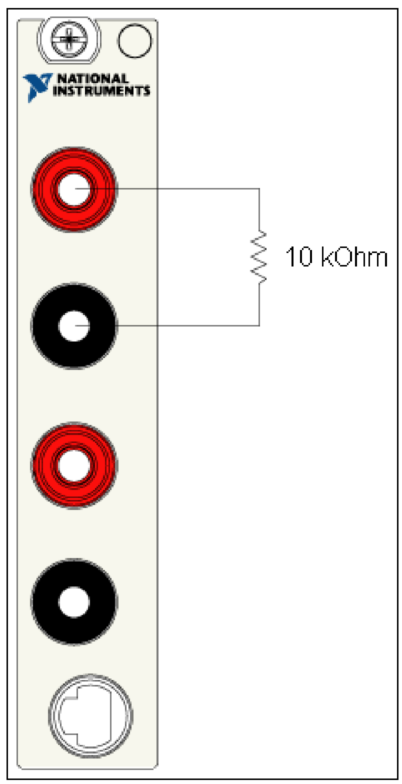

Figure 3-1. 2-Wire Resistance Wiring Diagram

3. Click the 2-wire resistance measurement button.

4. Set the Range to **AutoRange**.

5. Observe the measured resistance.
6. Close the Soft Front Panel.

End of Exercise 3-1

Exercise 3-2 Programming the DMM

Objective: To demonstrate how to find calibration information and how to self-calibrate an NI 407x DMM.

This exercise has three parts.

Throughout this exercise, you will refer to the *NI Digital Multimeters Help* and the specifications document for your device. These documents are installed with the NI-DMM driver. You can access these documents at **Start»All Programs»National Instruments»NI-DMM»Documentation**. They are also available at `ni.com`.

Part 1

In Part 1 of the exercise, you learn about the measurement cycle of the NI PXI-4072 DMM and benchmarking, which allows you to find the measurement rate of the DMM for a given measurement setup. In this part of the exercise, you complete a VI that benchmarks an NI PXI-4072 DMM through simulation without attaching the actual device to the computer.

1. Open `Simple Single Point Benchmark.vi` in the `<Exercises>\DMM` directory.

2. Right-click the block diagram and navigate to **Measurement I/O» NI-DMM**.

3. Modify the block diagram to benchmark a simulated NI PXI-4072 as shown in Figure 3-2 using the following items:

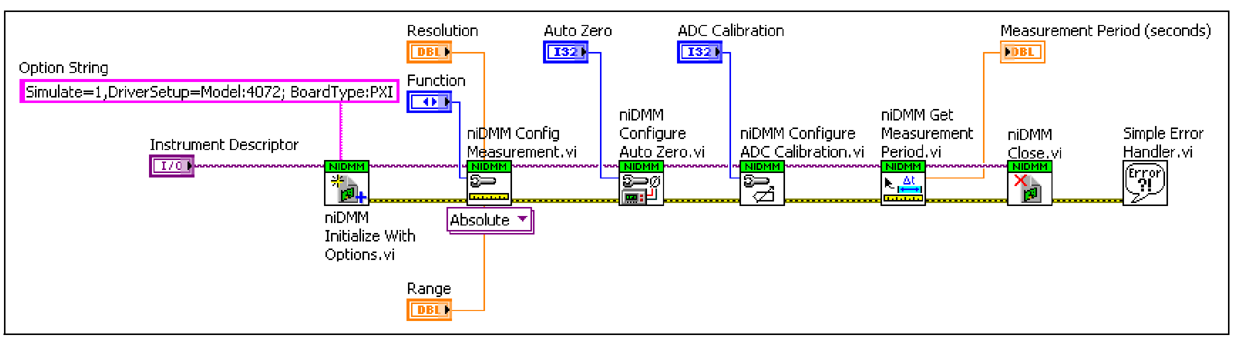

Figure 3-2. Simple Single Point Benchmark VI Block Diagram

❑ niDMM Initialize With Options VI—Opens a session to a DMM installed on your system or to a simulated DMM.

In this exercise you connect to a simulated NI PXI-4072.

– Wire the Instrument Descriptor input to the corresponding control on the block diagram.

– Wire the Option String input to the corresponding string constant on the block diagram.

  For more information on the allowed values for the Option String, refer to the *niDMM Initialize with Options* topic of the *NI Digital Multimeters Help*.

❑ niDMM Config Measurement VI—Configures the Function, Range, and Resolution for your measurement.

– Click the menu selector and select **Absolute Resolution**.

– Wire the Function, Resolution, and Range inputs to the corresponding controls on the block diagram.

❑ niDMM Configure Auto Zero VI—Enables or disables AutoZero.

– Wire the Auto Zero input to the corresponding control on the block diagram.

– Notice that the Auto Zero control is an enum control with three values: ON, ONCE and OFF.

  For more information on these three values, refer to the *niDMM Configure Auto Zero VI* topic in the *NI Digital Multimeters Help*.

❑ niDMM Configure ADC Calibration VI—Enables or disables ADC Calibration.

– Wire the ADC Calibration input to the corresponding control on the block diagram.

– Notice that the ADC Calibration control is an enum control with two values: ON and OFF.

  For more information on these two values, refer to the *niDMM Configure ADC Calibration VI* topic in the *NI Digital Multimeters Help*.

- ❑ niDMM Get Measurement Period VI— Finds the reading rate of the DMM for a given measurement setup.

  Use this VI after you have completely configured your measurement and immediately before you read your measurement.

  – Wire the Measurement Period output to the corresponding indicator on the block diagram.

- ❑ niDMM Close VI
- ❑ Simple Error Handler VI

4. Complete wiring the block diagram as shown in Figure 3-2.
5. Arrange your front panel to look similar to the one shown in Figure 3-3.

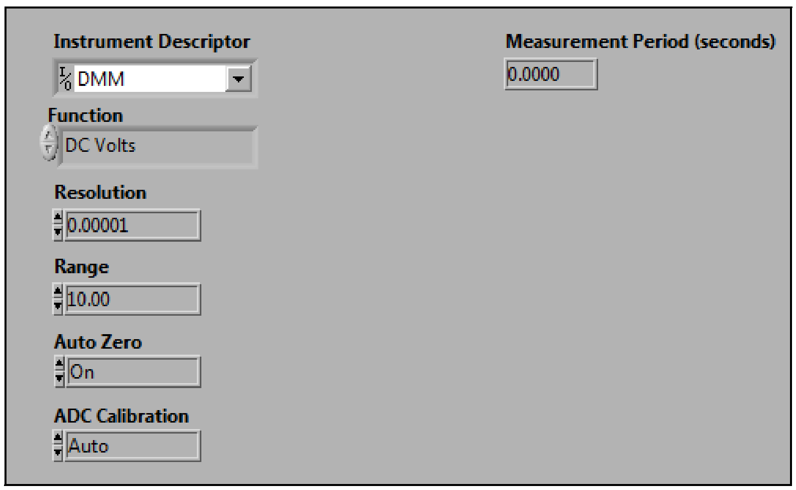

Figure 3-3. Simple Single Point Benchmark VI Front Panel

6. Save the VI.
7. Set the front panel input values to those listed in Table 3-1.

Table 3-1. Input Values for Simple Single Point Benchmark VI Front Panel

Control	Input Value
Function	DC Volts
Resolution	10 µ
Range	10
AutoZero	ON
ADC Calibration	ON

8. Run the VI and record the resulting measurement period for this first configuration here: ____________________.

At this point, you know the reading rate of the DMM for a specific measurement setup. Could your reading rate be faster if you disabled AutoZero or ADC Calibration? If so, how much faster?

In the next steps of this exercise, you disable AutoZero and ADC Calibration to determine how much they contribute to the length of the measurement period. Then you measure the reading rate again and compare the results with previous ones. You also find out how the other parts of the DMM measurement cycle contribute to the total measurement period by looking at the default values used by the NI-DMM driver.

9. Enter the measurement period from Step 8 in the **Total Time** row of Table 3-2.

   Notice that Table 3-2 has the same structure as the DMM Measurement Cycle diagram in the *DMM Measurement Cycle* topic in the *NI Digital Multimeters Help* under the NI 4072 device book.

Table 3-2. Results from Part 1

Cycle Phase	Time
Settling Time	
Aperture Time	
ADC Calibration	
Auto Zero	
Switch Time	
Total Time	

10. Set Autozero to OFF and run the VI again. Record this measurement here: ____________________.

Note When not simulating or when interested in also taking a reading, you should call niDMM Read VI or niDMM Initiate VI and niDMM Fetch VI after you run the niDMM Get Measurement Period VI.

11. Subtract the measurement period you measure in Step 10 from the one that you recorded in the **Total Time** row in Table 3-2, and enter this result under the **AutoZero** row of Table 3-2.

12. Set ADC Calibration to OFF and run the VI again. Record this measurement here: ____________________.

13. Subtract the measurement period you measured in Step 12 from the one that you measured in Step 10. Enter this result under the **ADC Calibration** row of Table 3-2.

14. The value you measured in Step 12 represents the duration of the Switching Time, Settling Time, and Aperture Time. The default Aperture Time and Settling Time values used by the driver depend on the range and resolution chosen.

    The measurement you configured in Step 7 was a DC Volts 6 ½ resolution measurement. Refer to the DC Volts specifications table in the specification document for your device for a quick reference on the maximum resolution for each range. In the case of the 10 V range, the maximum resolution is 10 µV, which corresponds to 6 ½ digits of resolution.

    For the default values for Settling Time and Aperture Time used by the NI-DMM driver for a DC V 6 ½ measurement, refer to the *DMM Measurement Defaults* topic in the *NI Digital Multimeters Help* under the NI 4072 device.

    Enter the appropriate values under columns **Settling Time** and **Aperture Time** in Table 3-2.

15. Add the **Settling Time** and **Aperture Time** you entered in Table 3-2, and subtract this value from the measurement period from Step 12. This difference corresponds to the Switching Time that the DMM requires before taking each measurement. Enter this value in the **Switch Time** row of Table 3-2.

Note NI-DMM queries the hardware for its current state before configuring the device. If your DMM has not been reset, the settling time could sometimes be shorter if the hardware is already switched to the configuration you want.

Conclusion

You have now benchmarked the measurement period of the DMM under a specific configuration. You have also determined how much each part of the DMM measurement cycle contributes to the total measurement period. There are so many different combinations of features you could use to configure your DMM to take a measurement that it is not practical to provide a table with different measurement periods. That is why benchmarking and the simulation mode are so useful.

Part 2

In Part 2 of this exercise, you learn how to programmatically change the parts of the DMM measurement cycle.

1. Open `Simple Single Point Benchmark.vi` in the `<Exercises>\DMM` directory.

2. On the block diagram, open the Context Help. Move your mouse over the niDMM Configure Measurement VI. In the Context Help window, click the link for the VI to open the detailed help.

   Notice that the niDMM Configure Measurement VI uses the values entered in the Range, Resolution, and Function parameters to write to the Range, Absolute Resolution, and Function properties respectively. Therefore, you can set the values for these properties either by using the niDMM Configure Measurement VI or by writing directly to the properties using a Property Node.

   NI-DMM uses the values of Function, Range, and Resolution to set the values for each part of the measurement cycle, as shown in the *DMM Measurement Defaults* topic in the *NI Digital Multimeters Help* under the NI 4072 device.

3. Close `Simple Single Point Benchmark.vi`.

4. Open `Advanced Single Point Benchmark.vi` in the `<Exercises>\DMM` directory.

5. Modify the block diagram to use a property node to configure the measurement, as shown in Figure 3-4.

   Notice that there is not an input into the property node for the resolution. The Aperture Time defines the resolution of the measurement. In general, the longer the aperture time, the better the resolution. In this exercise, you override the Aperture Time property manually, so specifying the resolution through the property node is not necessary.

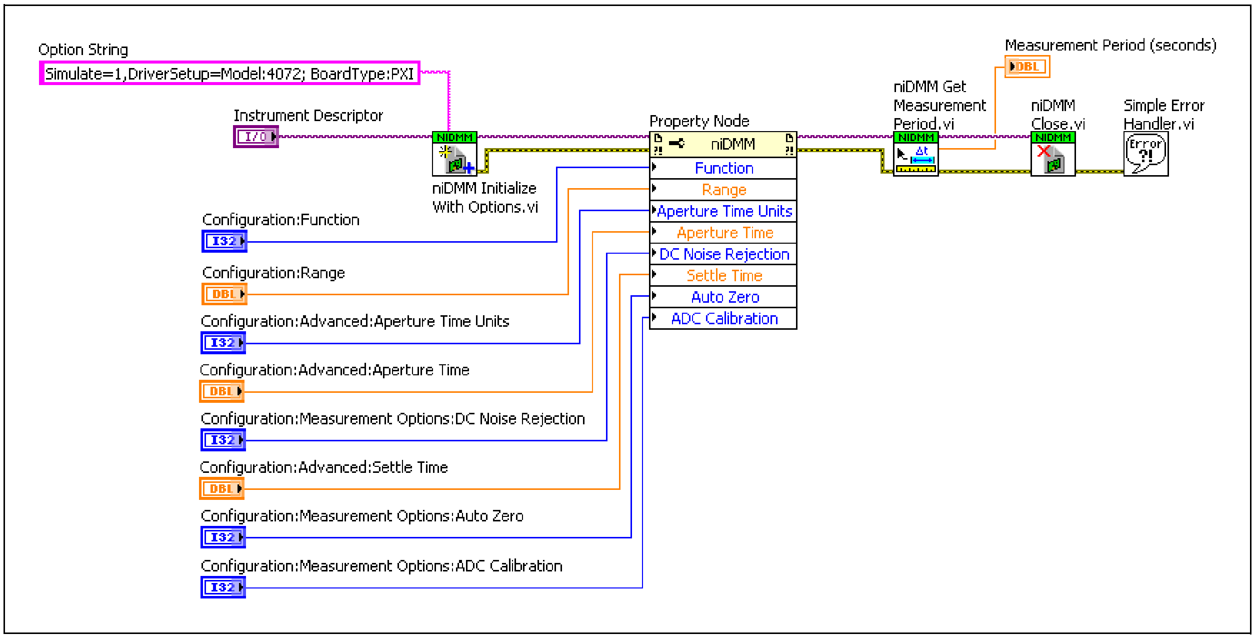

Figure 3-4. Advanced Single Point Benchmark VI Block Diagram

❑ Place an niDMM Property Node on the block diagram.

– Expand the node to display eight different options, as shown in Figure 3-4.

– Right-click the top of the node and select **Change All to Write**.

– Click each property and select each of the following respectively:

Configuration»Function

Configuration»Range

Configuration»Advanced»Aperture Time Units

Configuration»Advanced»Aperture Time

Configuration»Measurement Options»DC Noise Rejection

Configuration»Advanced»Settle Time

Configuration»Measurement Options»Auto Zero

Configuration»Measurement Options»ADC Calibration

Note You must set the Aperture Time Units before the Aperture Time, otherwise the driver uses the default value of seconds instead of power-line cycles.

❑ Wire the niDMM Property Node inputs to the corresponding controls on the block diagram.

6. Arrange your front panel to look similar to Figure 3-5.

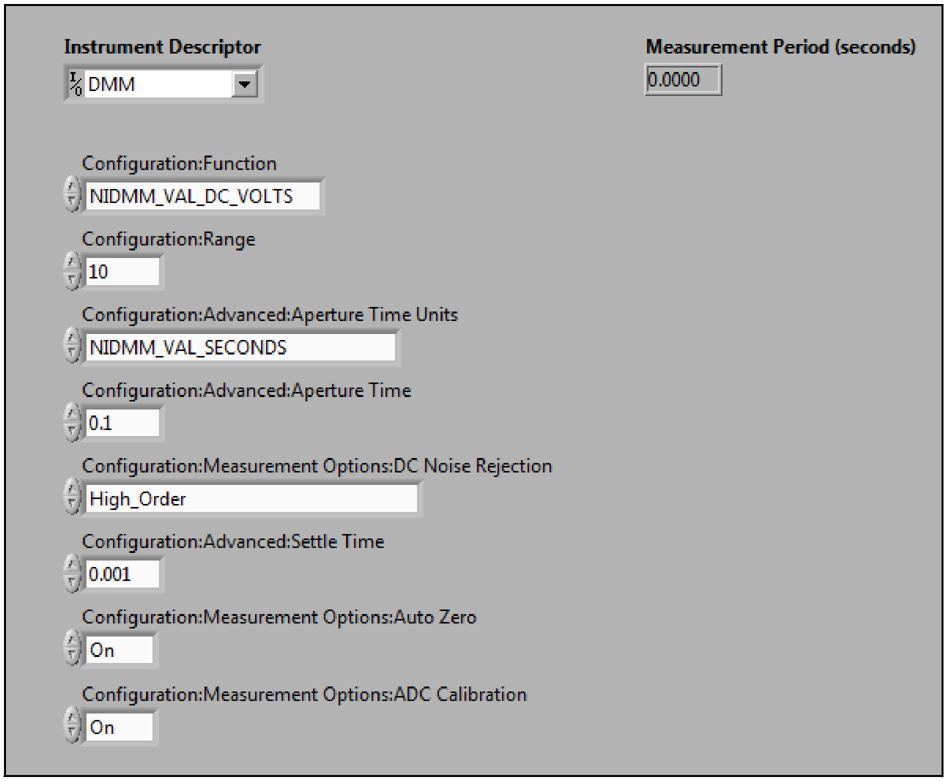

Figure 3-5. Advanced Single Point Benchmark VI Front Panel

7. Set the front panel input values to those listed in Table 3-3.

Table 3-3. Input Values for Advanced Single Point Benchmark VI Front Panel

Control	Input Value
Function	NIDMM_VAL_DC_VOLTS
Range	10
Aperture Time Units	NIDMM_VAL_SECONDS
Aperture Time	0.1
DC Noise Rejection	High_Order
Settling Time	0.001
AutoZero	ON
ADC Calibration	ON

8. Run the VI. Enter the measurement period in the **Total Time** row of Table 3-4.

Table 3-4. Results from Part 2

Cycle Phase	Time
Total Time	

Notice that the **Total Time** in Table 3-4 is the same as the **Total Time** in Table 3-2. If you were to calculate the Aperture Time, Auto Zero, ADC Calibration, Settling Time, and Switch Time following steps similar to the ones you took to fill out Table 3-2, your results would match the results in Table 3-2. Also notice that the switching time cannot be set but you can always measure it.

9. Change the DC Noise Rejection property to another value and run the VI again. Notice that this does not affect the measurement period. DC Noise Rejection adjusts the weighting of the samples taken during the Aperture Time. The frequencies filtered are a function of the Aperture Time. For more information about the possible values of DC Noise Rejection, refer to the *DC Noise Rejection* topic in the *NI-Digital Multimeters Help* under the NI 4072 device.

Conclusion

Using configuration VIs to configure your DMM is functionally equivalent to writing the values directly to the Properties. Property Nodes allow you to perform advanced configuration, such as setting the aperture time and settling time manually.

Part 3

1. Open `Advanced Single Point Benchmark.vi` and save it as `Advanced Multi-Point Benchmark.vi` in the `<Exercises>\DMM` directory.
2. Modify the block diagram as shown in Figure 3-6.

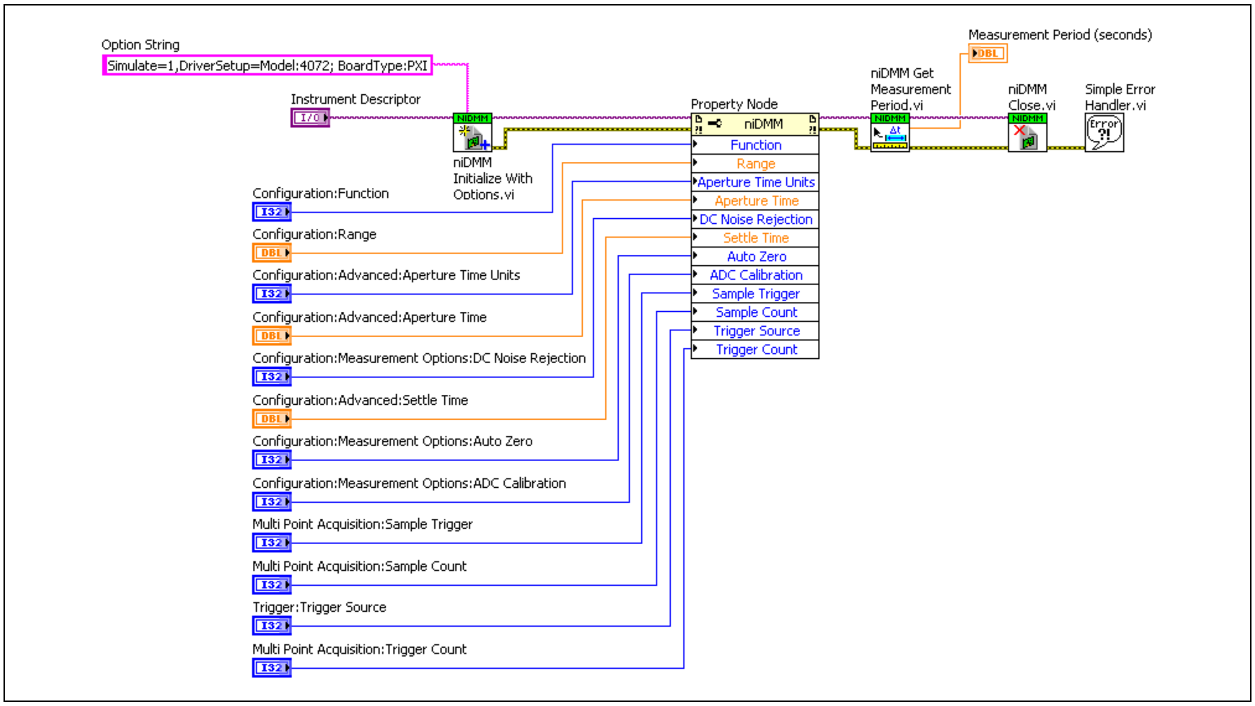

Figure 3-6. Advanced Multi-Point Benchmark VI Block Diagram

- ❑ Expand the property node so that four more elements are available. Verify that the properties are in write mode and if not, right-click each property and select **Change to Write**.
- ❑ Click each property and select the following respectively:
  - **Multi Point Acquisition»Sample Trigger**
  - **Multi Point Acquisition»Sample Count**
  - **Trigger»Trigger Source**
  - **Multi Point Acquisition»Trigger Count.**

  Setting these properties allows you to do multi-point acquisitions. These properties configure the triggers and the number of measurements to be taken.

Keep in mind that as in Part 2, attributes can be written through configuration functions instead of writing directly to the Properties. Hence, the trigger source can also be configured through the niDMM Configure Trigger VI function, and the trigger count, sample count, and sample source can be configured with the niDMM Configure Multipoint VI.

❑ Create controls for each of these properties by right-clicking each input and selecting **Create»Control**.

3. Arrange your front panel to look similar to the one shown in Figure 3-7:

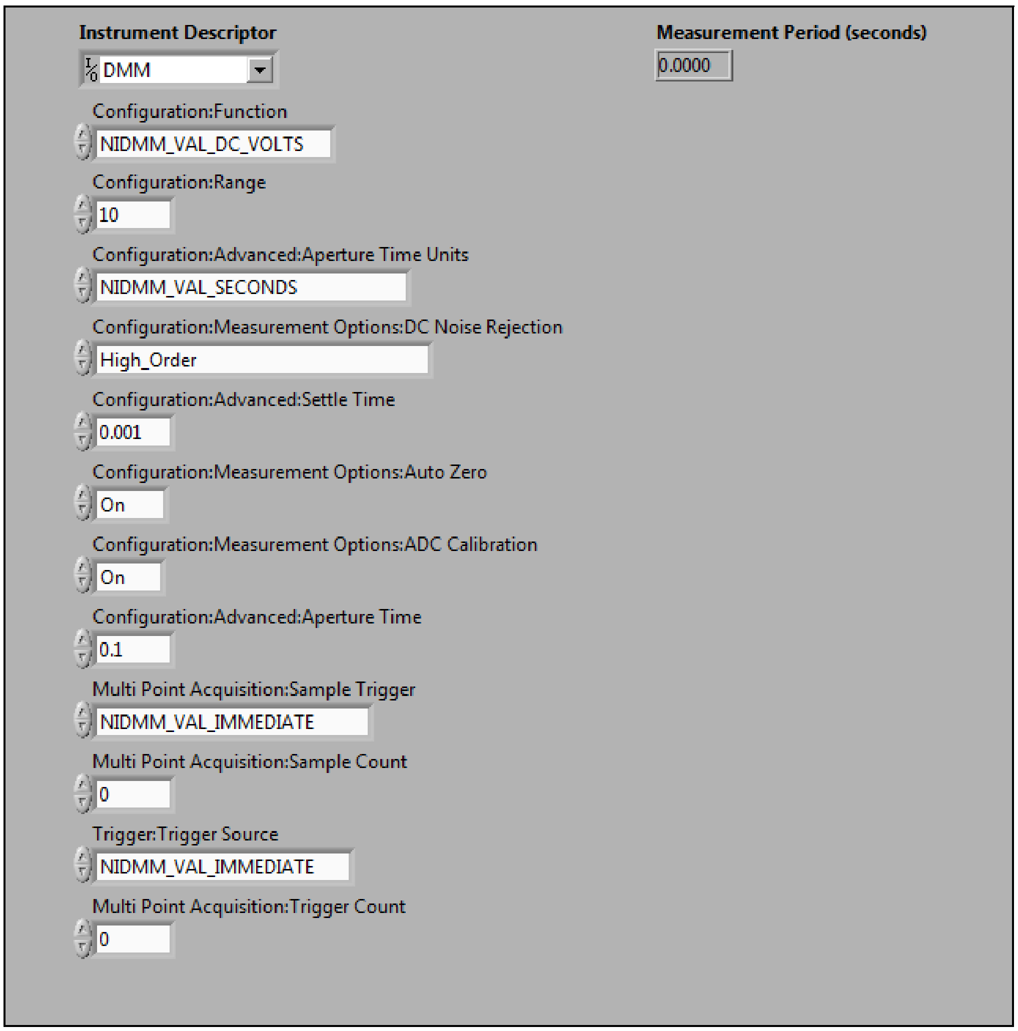

Figure 3-7. Advanced Multi-Point Benchmark VI Front Panel

4. Save the VI.

5. Set the front panel values to the ones listed in Table 3-5.

Table 3-5. Input Values for Advanced Multi-Point Benchmark VI Front Panel

Control	Input Value
Function	NIDMM_VAL_DC_VOLTS
Range	10
AutoZero	ON
ADC Calibration	ON
Settle Time	0.001
Aperture Time Units	NIDMM_VAL_SECONDS
Aperture Time	0.1
DC Noise Rejection	High_Order
Sample Trigger	Immediate
Sample Count	1
Trigger Source	Immediate
Trigger Count	1

6. Run the VI and record the resulting measurement period here: ____________________. Notice that this is the same as the total time recorded in Parts 1 and 2.

   This measurement period is the same because all three measurements have the same configuration. In a multi-point acquisition, the total number of measurements is equal to the Sample Count multiplied by the Trigger Count. In the configuration shown in Figure 3-7, both the Sample and Trigger Counts are set to 1 which corresponds to a single-point acquisition as in Parts 1 and 2.

7. Change the Sample Count value to `10`. Run the VI and record the resulting measurement period here: ____________________.

   Notice that the measurement period is shorter than the previous configuration. Anytime a multi-point acquisition occurs, the first measurement always takes longer than subsequent ones. The Get Measurement Period VI returns the measurement period of the second measurement when more than one is requested.

   The first measurement also takes longer than subsequent ones because of switching. In an immediately triggered multi-point acquisition, the switching times of subsequent measurements are optimized to their minimum, microsecond-level values because all of the measurements are on the same signal.

8. Change the Settle Time value to `-1`. Run the VI and record the resulting measurement period here: ____________________.

   Setting the Settle Time to –1 sets its attribute to Auto. This allows NI-DMM to optimize this setting based on other measurement attributes.

   Notice that the measurement period is even shorter with this configuration. NI-DMM optimized the Settling Time to its minimum value because in an immediately triggered multi-point measurement there is no need to wait for the input circuits to settle before taking the measurement because the same signal is being measured multiple times.

   It is always faster to do a multi-point acquisition instead of doing repeated single-point acquisitions. For more detail on the timing sequence of the DMM acquisition, refer to the *DMM Measurement Cycle* topic of the *NI Digital Multimeters Help* under the NI 4072 device. For more information on triggers and trigger sources, enter the keyword `trigger` into the index tab of the help file.

9. Open the Maximizing DC Reading Rate example VI found under `<LabVIEW>\examples\instr\niDMM\Performance Examples`. This program can be used to benchmark the precision of measurements using a real signal input to the DMM. Close the VI without saving it.

Conclusion

Benchmarking is a simple way to find out the timing and precision characteristics of your specific measurement with or without using the actual hardware. Manually entering values overrides NI-DMM's ability to make optimizations in the measurement cycle but gives more control to the programmer.

End of Exercise 3-2

Notes

5

DMM and Switches

Exercise 5-1 Scanning Modes

Objective: Investigate the synchronous scanning mode and handshaking scanning mode.

Part A: Synchronous Scanning Mode

In the NI Example Finder, select **Hardware Input and Output»Modular Instruments»NI-SWITCH (Switches)»niSwitch DMM Switch Synchronous Scanning.vi**.

This example demonstrates how to scan a series of channels on a switch module and take measurements with an NI digital multimeter using synchronous scanning.

The DMM takes a measurement and generates a digital pulse, called the Measurement Complete (MC) event. When the switch receives this digital pulse, it advances to the next entry in its scan list. 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 at least the time needed for the switch to activate and settle.

To use this example with your switch, complete the following steps:

Switch Setup

1. Verify that the chassis is identified in Measurement & Automation Explorer.

2. On the front panel, in the SWITCH section, set the **resource name** control to the appropriate switch resource name.

3. Set the **topology name** control to `2503/2-Wire 24x1 Mux`.

4. Set the **scan list** string control to `ch0:5->com0;`

5. Set the **trigger input** control to `TTL0`. Be sure to select the same TTL line for both the **trigger input** for the switch and the **measurement complete destination** for the DMM.

Note For more information on setting up switches and determining these values, refer to the *NI Switches Help*. Also, to determine if your switch supports scanning, the scan list syntax, and the valid channel names and valid resource names for your switch module, refer to the *NI Switches Help*.

DMM Setup

1. In the DMM section, set the **resource name** control to the appropriate DMM resource name.
2. Set the **measurement type** control to `DC Volts`.
3. Set the range to 10 V by setting the **range** control to `10`.
4. Set the resolution to 100 uV by setting the **resolution** control to `100u`.
5. Set the **sample count** control to `10`.
6. Set the sample interval to 0.10 seconds by setting the **sample interval** control `0.10`.
7. Set the measurement complete destination control to `TTL0`. Be sure to select the same TTL line for both the **trigger input** for the switch and the **measurement complete destination** for the DMM.

Note For more information on setting up your DMM and determining these values, refer to your NI DMM documentation.

Block Diagram

Go to the block diagram and observe the following sections of code.

1. Section A: The VI configures the switch first, which sets the triggers and scan list.
2. Section B: Next, the VI configures the DMM, which sets the function, range, resolution, triggers, and number of points to take.
3. Section C: When the VI initiates the switch, it connects the first channel in its scan list, enters the wait for trigger state, and allows the rest of the program to continue.
4. Section D: When the VI initiates the DMM, the DMM configures its hardware according to the settings from Step 2 and takes a measurement. This measures the first connection in the switch scan list. The DMM sends its Measurement Complete event signal to the switch to advance to the next connection. Then the switch moves to the next entry in its scan list and waits for a new trigger. The DMM then takes a new measurement after the interval time set in Sample interval parameter has elapsed. This operation repeats until the number of

measurements is equal to the Sample Count. When all the points have been acquired, they are returned to the user (fetch) and the DMM session is closed.

5. Section E: The VI terminates the scanning operation, closes the session to the switch, and displays errors if any.

Observe

1. Go the front panel.
2. Run the VI and observe the results.
3. Close the VI when finished.

Note For information about connecting signals to your switch module, refer to the *NI Switches Getting Started Guide* and *NI Switches Help*.

Part B: Handshaking Scanning Mode

In the NI Example Finder, select **Hardware Input and Output»Modular Instruments»NI-SWITCH (Switches)»niSwitch DMM Switch Handshaking.vi**.

This example demonstrates how to scan a series of channels on a switch module and take measurements with an NI digital multimeter using handshaking.

First, the DMM is initiated and waits for a digital pulse from the switch before taking any measurements. When the switch scanning task is started, it connects the first channel in its scan list, waits for the channel to settle and generates a digital pulse called the Scan Advanced event. When the DMM receives this digital pulse, it takes the first measurement and generates a digital pulse called the Measurement Complete (MC) event. When the switch receives this digital pulse, it advances to the next entry in its scan list and this continues.

To use this example with your switch, complete the following steps:

Switch Setup

1. On the front panel, in the SWITCH section, set the **resource name** control to the appropriate switch resource name.

2. Set the **topology name** control to `2503/2-Wire 24x1 Mux.`

3. Set the **scan list** string control to `Ch0:10->com0;`

4. Set the **trigger input** control to `TTL0`. Be sure you select the same TTL line for the **trigger input** for the switch and the **measurement complete destination** for the DMM.

5. Set the **scan advanced output** control to `TTL1`. Be sure to select the same TTL line for the **scan advanced output** for the switch and the **trigger source** for the DMM.

Note To determine if your switch supports scanning, the scan list syntax, and the valid channel names and valid resource names for your switch module, refer to the *NI Switches Help*.

DMM Setup

Refer to your NI DMM documentation to set up your DMM.

1. In the DMM section, set the **resource name** control to the appropriate DMM resource name.

2. Set the **measurement type** control to `DC Voltage`.

3. Set the range to 10 V by setting the **range** control to `10`.

4. Set the resolution to 1 mV by setting the **resolution** control to `1m`.

5. Set the **samples to fetch at a time** control to `4`.

6. Set the **measurement complete destination** control to `TTL0`. Be sure you select the same TTL line for the trigger input on the switch and the measurement complete destination on the DMM.

7. Set the **trigger source** control to `TTL1`. Be sure to select the same TTL line for the **scan advanced output** for the switch and the **trigger source** for the DMM.

Block Diagram

Go to the block diagram and observe the following sections of code.

1. Section A: The VI configures the switch first, which sets the triggers and scan list. The scanning configuration is downloaded to the hardware by the niSwitch Commit VI.

2. Section B: Next, the VI configures the DMM, which sets the function, range, resolution, triggers and number of points to take. When the DMM initiates, it configures its hardware according to the settings and waits for a trigger.

3. Section C: When the VI initiates the switch, the switch connects the first channel in its scan list, waits for the relays to settle and sends its Scan Advanced event to trigger the DMM for its first measurement. Once the DMM has taken a measurement, the DMM sends its Measurement Complete event to the switch to advance to the next entry in the scan list.

4. The DMM returns to the user the number of measurements specified in the samples to fetch at a time control. When the stop button is pushed the acquisition stops.

5. The VI terminates the scanning operation, closes the session to the switch, and display errors if any.

Observe

1. Go the front panel.
2. Run the VI and observe the results.
3. Close the VI when finished.

Note Refer to the *NI Switches Getting Started Guide* and *NI Switches Help* for information about connecting signals to your switch module.

Notes

A Slides

This appendix contains the slides for the *Modular Instruments—Digital Multimeter (DMM)* course.

Topics

A. Instrument Fundamentals

B. DMM Terminology

C. Using the DMM

D. Advanced DMM Topics

E. DMM and Switches

Lesson 1
Instrument Fundamentals

TOPICS

A. DMM Instrumentation
B. DMMs versus DAQ
C. Common Measurements
D. Benefits of NI DMMs

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A. DMM Instrumentation



Handheld DMMs
- 3½ - 5½ digits
- Portable, general purpose
- Most Common

Benchtop DMMs
- 5½ - 8½ digits
- Stationary, dedicated
- Sometimes programmed with GPIB, LAN, USB, Serial

NI DMMs
- 5½ - 7½ digits
- Stationary or Portable
- PCI, PXI, USB,
- Used with LabVIEW or text-based languages for Automated Test

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A. DMM Instrumentation

- Digital Multimeters (DMMs) are specialized in taking flexible, high resolution measurements
- Low to medium acquisition speeds
- High resolution
- Measures current or resistance in addition to voltage
- Different form factors: PXI, PCIe, PCI, USB



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B. DMMs vs. Multifunction DAQ

Multiple Measurement Types
- Higher resolution
- Higher voltage and current ranges
- Higher level of signal conditioning and isolation
- DMMs do not specify a reading rate
- Reading rate is dependent on configuration

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B. DMMs vs. Multifunction DAQ (cont) - Hidden

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C. Common Measurements

Primarily used for high resolution, slow sampling rate applications

DC Measurements	AC Measurement
Voltage Current Resistance Diode Measurement	RMS Voltage RMS Current Capacitance Inductance

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D. Benefits of NI DMMs

Software Support in NI LabVIEW and SignalExpress

The NI 407x series of DMMs offer unique capabilities

- Isolated Digitizer Mode at up to 1.8 MS/s
- Industry Leading Accuracy
- 2-year Calibration Cycle

- USB-4065 & PCMCIA-4050 for portable measurements

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Summary

- DMMs used for high resolution, low acquisition speed applications
- Capable of making various DC and AC measurements
- Common measurements: voltage, current, resistance
- Compared to a DAQ device, high level of signal conditioning, isolation, and range of operation

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Lesson 2
DMM Terminology

TOPICS

A. Accuracy
B. Resolution
C. Sensitivity

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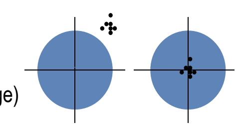
A. Accuracy

Accuracy represents the uncertainty of a given measurement

Device Uncertainty is usually specified by the manufacturer in three ways:

- (% Reading) + Offset
- (% Reading) + (% Range)
- ±(ppm of reading + ppm of range)
- 1 ppm = 0.0001%

where ppm is parts per million



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Temperature Induced Uncertainty

- Temperature Induced Uncertainty component considered when a measurement is made outside the calibrated temperature range
- Measurements made ±5 °C with respect to calibration temperature still accurate according to device specification
- Temperature Induced Uncertainty calculated as product of temperature coefficients (Tempco) and temperature difference
- Tempco is usually specified as:
  (ppm of reading + ppm of range) per °C

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Calculating Accuracy: Example 1

Consider a measurement:

- Made with NI 4070 calibrated at 23 °C
- 6½ digit measurement of 5 VDC signal
- Selected 10 V range
- Within 2-year period of last calibration

What is the accuracy?

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Calculating Accuracy: Example 1 Answer

DC Voltage ± (ppm of reading + ppm of range)

Range	Resolution	Input Resistance	24 Hr $T_{cal} \pm 1$ °C	90 Day $T_{cal} \pm 5$ °C	2 Year $T_{cal} \pm 5$ °C	Tempco/°C (0 °C–50 °C) Without Self-Cal	With Self-Cal
100 mV[4]	100 nV	>10 GΩ,10 MΩ	10 + 10	30 + 20	40 + 20	4 + 5	0.3 + 0.3
1 V	1 μV	>10 GΩ,10 MΩ	6 + 2	20 + 6	25 + 6	2 + 1	0.3 + 0.3
10 V	10 μV	>10 GΩ,10 MΩ	4 + 2	20 + 6	25 + 6	1 + 1	0.3 + 0.3
100 V	100 μV	10 MΩ	6 + 2	30 + 6	35 + 6	4 + 1	0.3 + 0.3
300 V	1 mV	10 MΩ	6 + 6	30 + 20	35 + 20	4 + 3	0.3 + 0.3

Accuracy = ±(ppm of reading + ppm of range)
= ± (25 ppm x 5 V + 6 ppm x 10 V)
= ±185 μV

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Calculating Accuracy: Example 2

Consider taking a measurement in 38 ºC temperature.

DC Voltage ± (ppm of reading + ppm of range)

Range	Resolution	Input Resistance	24 Hr $T_{cal} \pm 1$ °C	90 Day $T_{cal} \pm 5$ °C	2 Year $T_{cal} \pm 5$ °C	Tempco/°C (0 °C–50 °C) Without Self-Cal	With Self-Cal
100 mV[4]	100 nV	>10 GΩ,10 MΩ	10 + 10	30 + 20	40 + 20	4 + 5	0.3 + 0.3
1 V	1 μV	>10 GΩ,10 MΩ	6 + 2	20 + 6	25 + 6	2 + 1	0.3 + 0.3
10 V	10 μV	>10 GΩ,10 MΩ	4 + 2	20 + 6	25 + 6	1 + 1	0.3 + 0.3
100 V	100 μV	10 MΩ	6 + 2	30 + 6	35 + 6	4 + 1	0.3 + 0.3
300 V	1 mV	10 MΩ	6 + 6	30 + 20	35 + 20	4 + 3	0.3 + 0.3

Temperature Induced Uncertainty must be considered.

Accuracy = ± (25ppm of 5V + 6 ppm of 10V)
+ [(1ppm x 5V + 1ppm x 10V) × (38-(23+5))] = ±335μV

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Calculating Accuracy: Example 3

Consider taking a 5 ½ measurement at 23 °C.

Additional Noise Errors for DC Voltage, Current, Resistance

Resolution	Additional Noise Error
5½ digits	10 ppm of range
5 digits	30 ppm of range
4½ digits	100 ppm of range

Accuracy = ± (25ppm x 5V + (6ppm + 10ppm) x10V) = ±285μV

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B. Resolution

Resolution is the smallest change in an input signal that produces a change in the output.

Resolution is specified by the manufacturer in three units:

- Bits
- Absolute Units of Resolution (AUR)
- Digits of Resolution

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Bits of Resolution

In an ideal situation, only quantization noise is present, so resolution can be represented as bits of resolution.

Bits of resolution refers to the number of bits on the analog-to-digital converter (ADC).

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Absolute Units of Resolution

Absolute unit of resolution represents the minimum change in voltage a device can measure.

For a given voltage measurement range, the [noise-free] absolute unit of resolution is:

$$\frac{\text{Total span for the Given Range (in volts)}}{\text{Number of ADC quantization Levels (counts)}}$$

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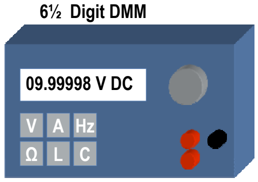
Digits of Resolution

Traditionally, 6½ digits referred to the number of digits displayed on the readout of boxed instruments.

Now, Digits of Resolution is a calculation.

This equation is in the *Resolution* topic in the *DMM Help*.

6½ Digit DMM



Full Digits (0-9): 6
Half Digit (0 or 1) : 1

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Noise and Digits of Resolution

- Real-world systems, noise must be considered.
- Higher level of noise produces lower effective resolution.
- Effective Number of Digits (ENOD) includes this noise.
- For example, a DMM ideally with 6 digits could be reduced to 5 digits. See Help file for these calculation.

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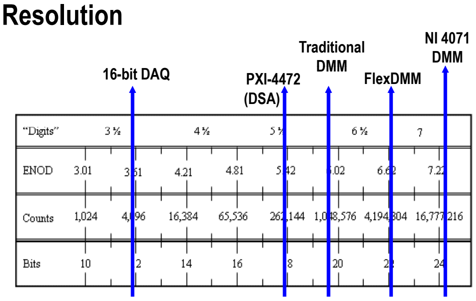
Relationship between Measures of Resolution



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C. Sensitivity

- Smallest change that can be meaningfully detected with the instrument .
- For example, assume the sensitivity of a digital multimeter is 100 nV. With this sensitivity, the digital multimeter can detect a 100 nV change in the input voltage.

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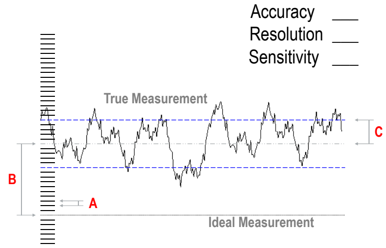
Summary – Quiz

Match the term to the aspect of the measurement.

Accuracy ___
Resolution ___
Sensitivity ___



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Lesson 3
Using the DMM

TOPICS

A. DMM Connections
B. Soft Front Panel
C. DMM Programming Flow

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A. DMM Connections

DMMs are used when accurate and high-resolution measurements are required

Common DMM Measurements:

- Voltage
- Current
- Resistance

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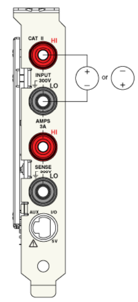
DMM Connection: Voltage Measurement



- NI DMMs can make DC and AC voltage measurements
- Connect the voltage to be measured to the top two HI and LO input connectors
- Measurement concerns:
  - Offset voltage
  - Noise rejection

For more information on:

DC Voltage Measurements

AC Voltage RMS Measurements

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DMM Connection: Current Measurement

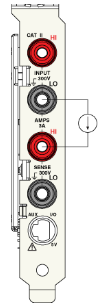
For all ranges, current flows through onboard precision shunt resistor.

Measurement concerns:

- Generated currents
- Leakage current
- Burden voltage

For more information on

DC and AC Current Measurements



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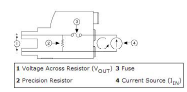
DMM Connection: Current Measurement

- Use a current shunt module for making measurements outside specified range.
- Current Shunt Modules:
  - NI CSM-10 A (0.01 Ω sense resistor)
  - NI CSM-200 mA (1.0 Ω sense resistor)



- When using external shunt set the voltmeter to DC V and perform conversion to current in SW.

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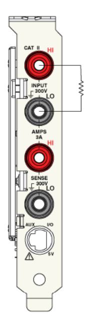
DMM Connection: Resistance Measurement



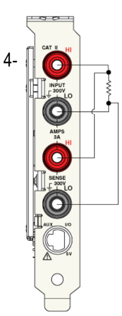
NI DMMs are capable of making 2-wire and 4-wire resistance measurements

Measurement Concerns:

- Lead resistance
- Thermal EMF
- Parallel resistance

For more information on

Resistance Measurements



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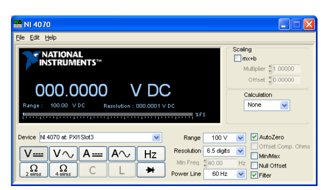
B. NI-DMM Soft Front Panel

Make measurements without any programming

Installed with NI-DMM driver



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Exercise 3-1: Using the NI-DMM Soft Front Panel

Measure the resistance using the NI-DMM Soft Front Panel

GOAL

C. NI-DMM Programming Flow

Programmed with NI-DMM driver

Support in the following Application Development Environments:

- LabVIEW
- LabWindows/CVI
- Microsoft Visual Basic
- Microsoft Visual C++

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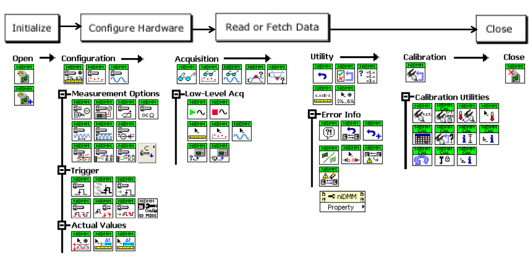
NI-DMM Programming Flow



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NI-DMM Programming Flow: Initialize

Initialize → Configure Hardware → Read or Fetch Data → Close

Open

niDMM Initialize –Opens a session to the DMM

niDMM Initialize With Options –Opens a session to a Simulated DMM

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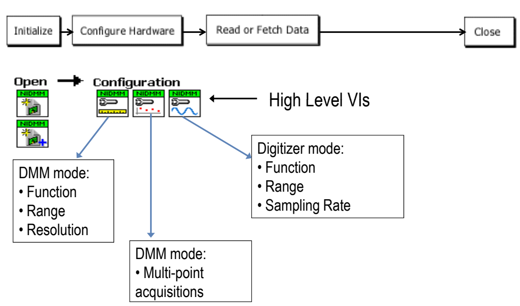
NI-DMM Programming Flow: Configure



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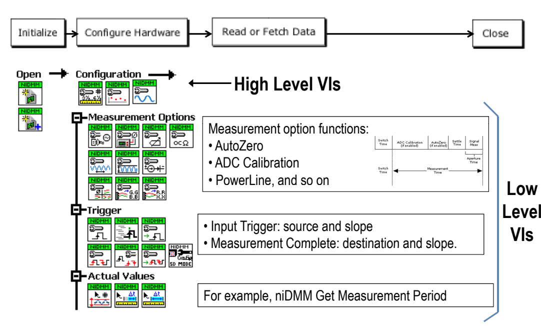
NI-DMM Programming Flow: Configure



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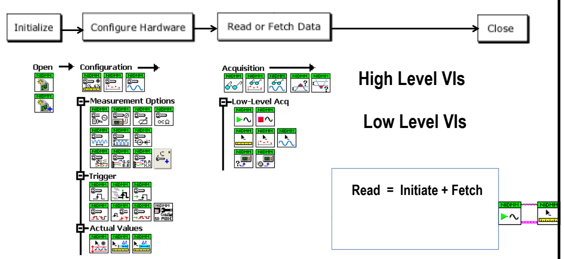
NI-DMM Programming Flow: Acquisition



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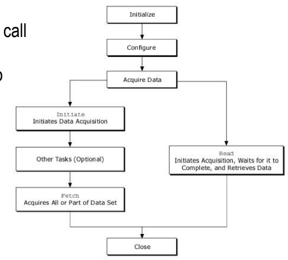
DMM Acquisition - Read vs. Fetch

niDMM Read–Combines niDMM Initiate and niDMM Fetch into one call

niDMM Initiate–Returns control to program, thus freeing up processor for other tasks while DMM is acquiring data

niDMM Fetch–Transfers acquired data from RAM to your application



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C. DMM Acquisition - Read vs. Fetch (cont.) - Hidden

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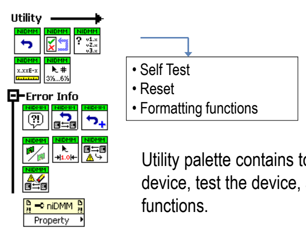
NI-DMM Programming Flow: Utility Palette



Utility palette contains tools to reset the device, test the device, and other functions.

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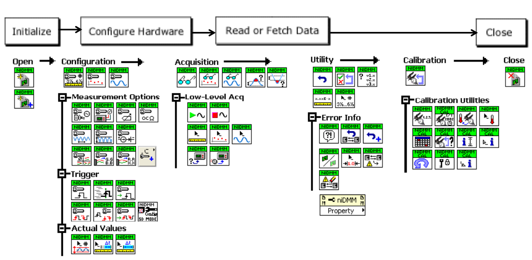
NI-DMM Programming Flow: Close



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Self-Calibration

To demonstrate how to find out calibration information and Self-Calibrate a 407x DMM.

DEMONSTRATION

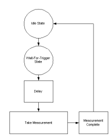
D. Programming with NI-DMM

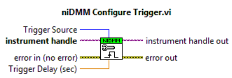
Single Point Measurement

After configuration, the DMM enters the idle state.

Once it is initiated, the DMM waits for a trigger.

Use niDMM Configure Trigger to specify trigger source and delay. The default trigger source is Immediate.





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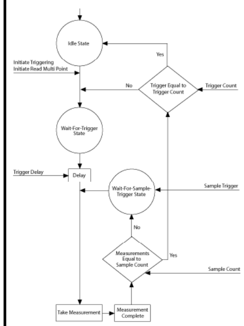
Programming with NI-DMM: Multipoint Measurement

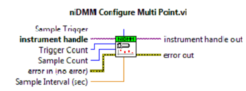


Multipoint Measurements

2 triggers

Use niDMM Configure MultiPoint to configure:

- Sample Trigger source (default is Immediate)
- Sample Trigger counts (default is 1)
- Trigger counts



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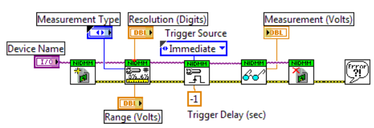
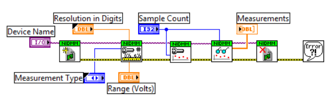
Programming with NI-DMM

Finite Measurements





In this example, sample count determines the number of samples acquired.

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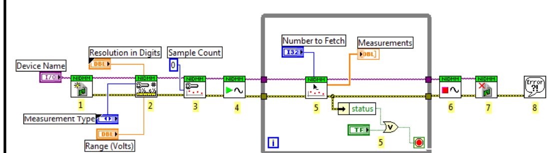
Programming with NI-DMM

Continuous Measurements



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Programming with NI-DMM : Sampling Rate

How do I set the Sampling Rate in DMM mode?

- Reading rate is not set directly. It is determined by:
  - Resolution (higher resolution = slower rate)
  - Function (for example, AC measurements take longer than DC measurements)
  - Range (settling time)
  - Enabled measurement enhancement functions
- This results in large number of different configurations
- Therefore, you need to benchmark the measurement period.

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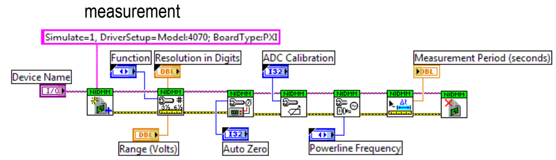
Programming with NI-DMM – Sampling Rate

How do I set the Sampling Rate in DMM mode?

- You can use simulation mode to benchmark measurement periods:
  - Use niDMM Initialize with Options to open a session to a simulated device
  - Use niDMM Get Measurement Period to benchmark measurement



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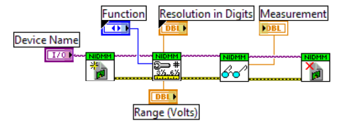
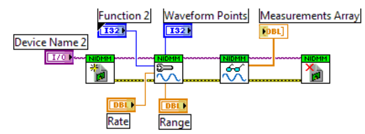
Programming with NI-DMM (cont.) – Hidden

Programming with NI-DMM :Digitizer Mode

DMM Mode

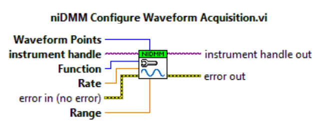


Digitizer Mode



NI-DMM Programming Flow : Waveform

- Use niDMM Configure Waveform Acquisition to set the sampling rate and the number of points (n) to acquire.

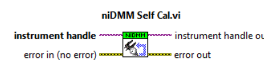


- Allowed sampling rate values: r = 1.8 M/z, where z =1,2,3,… 1.8 M
- Allowed aperture time: 8.89 µs < *t aperture* < 149 s
  where *t* aperture= n / r

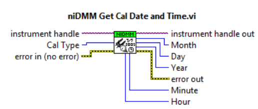
Programming with NI-DMM : Self-Calibration

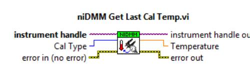
Self Calibration

Only supported by NI 407x.



Only calibrate if temperature has changed more than 5 °C or if 90 days have passed.





Extends amount of time required to have an external calibration to 2 years.

Exercise 3-2: Programming the DMM

Benchmark the measurement cycle for various configurations.

GOAL

Summary – Quiz

1) Which of the following are common DMM measurements?
   a) Voltage
   b) Current
   c) Resistance
   d) Pressure

Summary – Quiz

2) Use the ______ to make measurements without any programming.
   a) NI-DMM Soft Panel
   b) NI-DMM VIs
   c) LabVIEW

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Summary – Quiz

3) Which of the following shows the correct NI-DMM programming flow?
   a) Initialize > Configure Hardware > Read/Fetch Data > Close
   b) Initialize > Read/Fetch Data > Configure Hardware > Close
   c) Configure Hardware > Initialize > Read/Fetch Data > Close

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Lesson 4
Advanced DMM Topics

TOPICS

A. High Accuracy/Low Noise
B. Measurement Cycle
C. Optional Features

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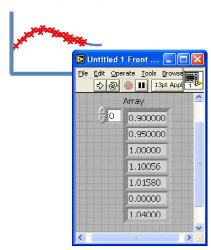
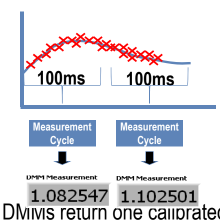
A. High Accuracy/Low Noise

DAQ devices return every sampled point.





DMMs return one calibrated reading made up of many sampled points.

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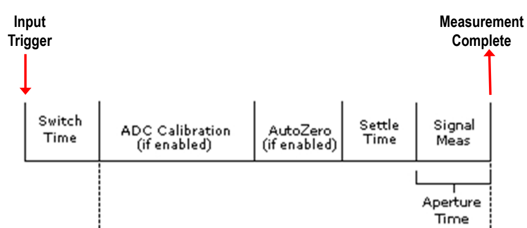
B. Measurement Cycle



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Switch Time

- Required to configure the internal analog circuitry of the DMM for the next measurement
- Cannot be controlled
- Multi-point acquisitions with same configuration, switching time is larger for the first sample
- In subsequent samples, the switching time is optimized to its minimum

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Auto Range

- Range of a measurement is the maximum absolute value of the signal being measured
- NI DMMs with auto range capabilities can calculate the approximate range for signal
- Enable auto range increases measurement period
- Available modes: ON, OFF, and ONCE

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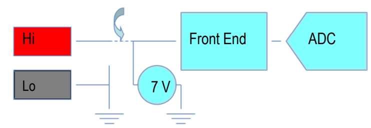
ADC Calibration

Compensates for gain errors by comparing reference measurements to calibrated information



Important for 7 ½!

Tips: -
Disable ADC calibration to increase speed
Increase reading rate up to 2x
Add 3 ppm/°C
Self-calibrate periodically

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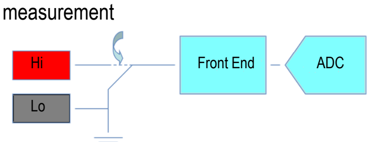
AutoZero

Compensates for offset errors by subtracting a zero reading from the measurement



Tips: -
Disable AutoZero to increase speed
Allow a 0 minute warm-up
Add 2 ppm/°C
Self-calibrate with temperature drift

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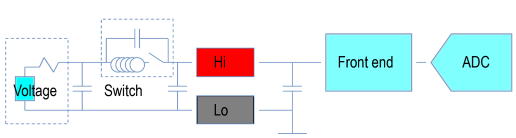
Using the AutoZero Feature

Demonstrate the usefulness of the AutoZero feature of the 407x DMM.

DEMONSTRATION

Settling Time

Allows transients to reach steady state before sampling



Settling Time = kRC
Important for resistance > 10 k Ω

Tip: To improve resolution, increase settling time when switching

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Aperture Time

- Aperture time is the period during which the ADC is reading the input signal.
- You can specify aperture time either in seconds or power line cycles (PLCs).
- Resolution, measurement speed and frequency rejection are functions of aperture time.

↑ Aperture time = ↑ Resolution ↓ Measurement Speed

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Aperture Time :DCNR

- Many measurements are taken during the aperture time and averaged to return a single sample
- Acquiring more points and averaging them cancels noise
- By adjusting the relative weight of the samples, can adjust sensitivity to different interfering frequencies

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Aperture Time : DCNR

- Three different modes for DCNR:
  - Normal
  - Second-order
  - High-order

DCNR Setting	Lowest Frequency for Noise Rejection
Normal	$>f_0=1/t_{aperture}$
Second-order	$>f_0=2/t_{aperture}$
High-order	$>f_0=4/t_{aperture}$

- The lowest frequency for DC noise rejection (DCNR) is a function of aperture time

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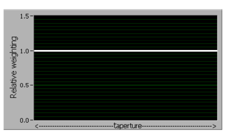
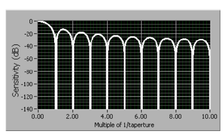
Aperture Time : DCNR

Normal rejection mode

- Emulate behavior of most traditional DMM
- Rejection of frequencies at multiples of *f0*, where $f0 = 1/t_{aperture}$





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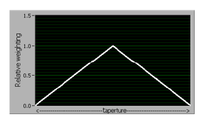
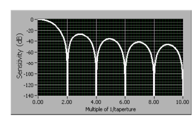
Aperture Time : DCNR

Second-order rejection mode

- Triangular weighting of measurement samples throughout the aperture time period
- Samples taken in the middle of aperture time weighted more
- Rejection of frequencies at multiples of *f0*, where $f0 = 2/t_{aperture}$

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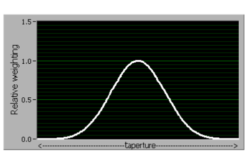
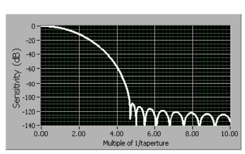
Aperture Time : DCNR

High-order rejection mode

Bell shaped weighting of measurement samples

Rejection of frequencies at multiples of *f0*, where $f0 = 4/t_{aperture}$.





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Aperture Time – DCNR (cont) - Hidden

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C. Optional Features

Capacitance/ Inductance Measurements (NI 4072)

Digitizer Mode (NI 407x)

- Allows DMM to sample at fixed time intervals and return waveform measurement
- Allow waveform measurements with large range and high isolation

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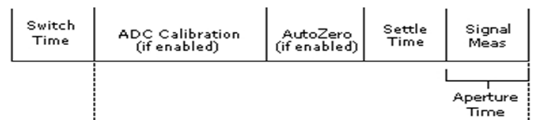
Summary – Quiz

Which of the following could you turn off to reduce your measurement time?



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Lesson 5
DMM and Switches

TOPICS

A. DMMs and Switching
B. Scanning mode : synchronous
C. Scanning mode: handshaking
D. DMM/Switch Connection
E. DMM/Switch Express

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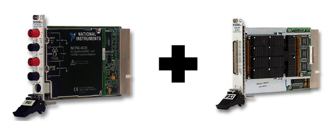
A. DMM and Switches

DMMs are often used with switches to extend the number of signals to which a DMM can be connected

DMMs are high performance, high precision devices, but only have one channel

Use switches to multiplex connections to multiple channels



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DMM and Switches : Scanning

Scanning on a switch is used when timing of a connection needs to be synchronized with hardware event (Measurement Completed event on DMM)

Scanning can be performed with most switches

- **All** SCXI switches except: 1160, 1161, 1163R, 1190, 1191
- **All** PXI switches

Two types of hardware-timed scan options:

- Synchronous scanning
- Handshaking scanning

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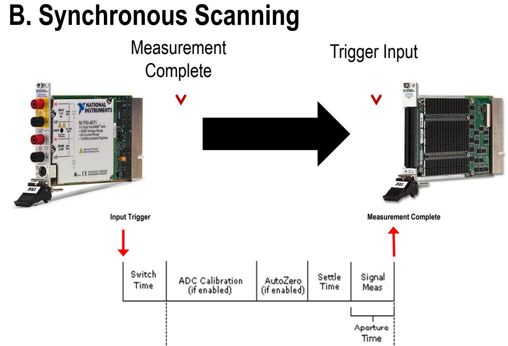
B. Synchronous Scanning



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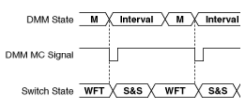
Synchronous Scanning



Program the DMM interval time between measurements to allow time for the switch to activate and settle.

where:
M = measurement
WFT = wait for trigger
S&S = switch and settle

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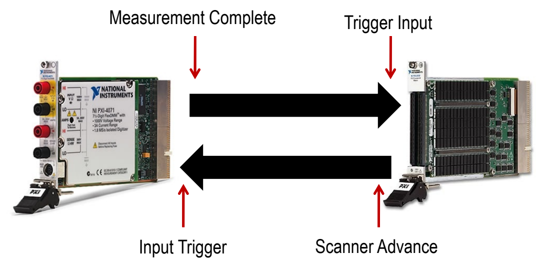
C. Handshaking Scanning



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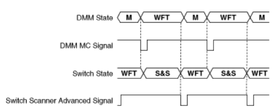
Scanning Mode: Handshaking



No longer need fixed intervals between measurements

Switching the switch and measurements on the DMM depend on triggers

where:
M = measurement
WFT = wait for trigger
S&S = switch and settle

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Exercise 5-1: Scanning Modes

Take measurements with an NI digital multimeter using synchronous scan mode and handshaking scan mode.

GOAL

D. DMM/Switch Control

Switch selection based on signal type and topology

NI DMMs often paired in PXI or SCXI switch system configurations

DMM can be used as a controller for the switch

Still need to physically connect the signal from the switch to the front panel of the DMM

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DMM/Switch Control: Configurations

There are several tables that describe the different configurations of a DMM and a switch.

The system configuration depends on the controlling module of the switch.

For more information on configuring the connection between a DMM and a switch, refer to *Scanning Switch Modules* in the *NI Digital Multimeter Help* and the Switch/DMM Hardware Configurations article in the KnowledgeBase.

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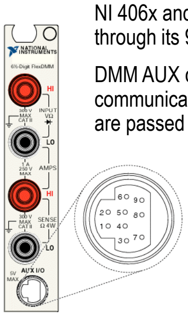
DMM/Switch Control: PXI + SCXI



NI 406x and NI 407x controls SCXI chassis through its 9-pin serial connector

DMM AUX connector is used for digital communication and triggering, no analog signals are passed

- Controls SCXI switch and digital modules as well as the NI SCXI-1124 analog output module

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DMM/Switch Control: PXI + SCXI (cont.) – Hidden)

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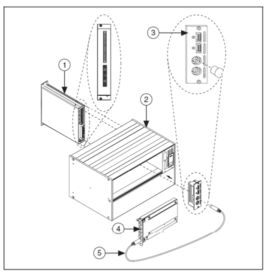
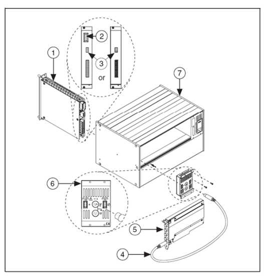
DMM/Switch Control: PXI + SCXI





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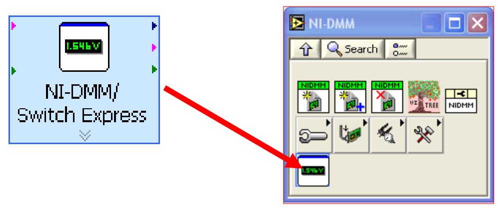
E. DMM/Switch Express VI



- NI-DMM 2.5 introduced the NI-DMM/Switch Express VI which automatically handles the triggering and coding required for synchronous or handshaking scanning modes
- NI DMM/Switch Express VI can be used independently without switches to make normal DMM measurements

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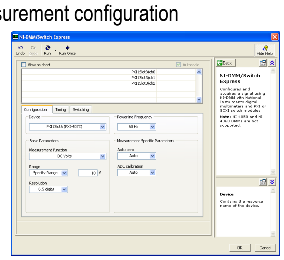
DMM/Switch Express VI: Configuration Tab

Configuration tab specifies which DMM device to use and the desired measurement configuration



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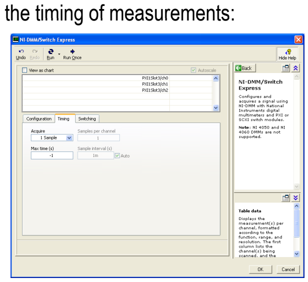
DMM/Switch Express VI: Timing Tab

Timing tab configures the timing of measurements:

- 1 Sample
- N Samples
- Continuous



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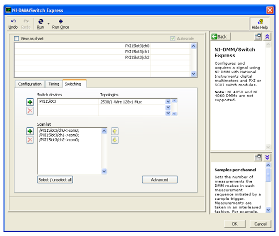
DMM/Switch Express VI: Switching Tab

Switching tab configures which switch and channels to use in scanning mode with the DMM



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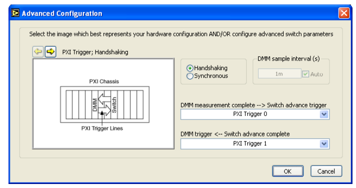
DMM/Switch Express VI: Advanced Configuration

Advanced Configuration dialog box configures what Scanning Mode to use as well as the trigger lines



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Summary – Quiz

1) True or False: DMMs are high resolution accurate devices with one channel.

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Summary – Quiz

2) DMMs are often used with ______ to extend the number of signals to which a DMM can be connected.
   a) Switches
   b) Resistors
   c) Calibration

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Summary – Quiz

3) Which of the following are types of hardware-timed scan methods?
   a) Synchronous Scanning
   b) Handshaking Scanning
   c) Calibration Scanning
   d) Auto Zero

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Summary – Quiz

4) Which of the following can generate the triggering and coding required for synchronous or handshaking scanning modes?
   a) DMM/Switch Express VI
   b) niDMM Initialize VI
   c) niDMM Read VI

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Additional Resources

DC Voltage Measurements
http://zone.ni.com/devzone/cda/tut/p/id/3226

AC Voltage RMS Measurements
http://zone.ni.com/devzone/cda/tut/p/id/2966

DC and AC Current Measurements
http://zone.ni.com/devzone/cda/tut/p/id/3225

Resistance Measurements
http://zone.ni.com/devzone/cda/tut/p/id/3981

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Additional Resources (Cont.)

Eliminating Accuracy Errors with Self-Calibration (Interactive tutorial)
http://zone.ni.com/wv/app/doc/p/id/wv-249

Switch/DMM Hardware Configurations
http://digital.ni.com/public.nsf/allkb/DED0DF9FD49D190486257124005
0871F

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  - Apply the cost of this course to your membership if you purchase within 30 days

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- ni.com/support
  - Access product manuals, KnowledgeBase, example code, tutorials, application notes, and discussion forums
- Info-LabVIEW: www.info-labview.org
- User Groups: ni.com/usergroups
- Alliance Program: ni.com/alliance
- Publications: ni.com/reference/books/
- Practice!

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Please complete the course survey

Thank you!

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B

Additional Information and Resources

This appendix contains additional information about National Instruments technical support options and Modular Instruments–DMM resources.

National Instruments Technical Support Options

Log in to your National Instruments `ni.com` User Profile to get personalized access to your services. Visit the following sections of `ni.com` for technical support and professional services:

- **Support**—Technical support at `ni.com/support` includes the following resources:
  - **Self-Help Technical Resources**—For answers and solutions, visit `ni.com/support` for software drivers and updates, a searchable KnowledgeBase, product manuals, step-by-step troubleshooting wizards, thousands of example programs, tutorials, application notes, instrument drivers, and so on. Registered users also receive access to the NI Discussion Forums at `ni.com/forums`. NI Applications Engineers make sure every question submitted online receives an answer.
  - **Standard Service Program Membership**—This program entitles members to direct access to NI Applications Engineers via phone and email for one-to-one technical support, as well as exclusive access to eLearning training modules at `ni.com/elearning`. All customers automatically receive a one-year membership in the Standard Service Program (SSP) with the purchase of most software products and bundles including NI Developer Suite. NI also offers flexible extended contract options that guarantee your SSP benefits are available ithout interruption for as long as you need them. Visit `ni.com/ssp` for more information.

    For information about other technical support options in your area, visit `ni.com/services` or contact your local office at `ni.com/contact`.
- **System Integration**—If you have time constraints, limited in-house technical resources, or other project challenges, National Instruments Alliance Partner members can help. The NI Alliance Partners joins system integrators, consultants, and hardware vendors to provide comprehensive service and expertise to customers. The program

ensures qualified, specialized assistance for application and system development. To learn more, call your local NI office or visit ni.com/alliance.

You also can visit the Worldwide Offices 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.

Other National Instruments Training Courses

National Instruments offers several training courses for Modular Instruments DMM users. These courses continue the training you received here and expand it to other areas. Visit ni.com/training to purchase course materials or sign up for instructor-led, hands-on courses at locations around the world.

National Instruments Certification

Earning an NI certification acknowledges your expertise in working with NI products and technologies. The measurement and automation industry, your employer, clients, and peers recognize your NI certification credential as a symbol of the skills and knowledge you have gained through experience. Visit ni.com/training for more information about the NI certification program.