CALIBRATION PROCEDURE

NI PXIe-4141

PXIe, 4-Channel, ±10 V, 100 mA, Precision PXI Source Measure Unit (SMU)

This document contains the verification and adjustment procedures for the NI 4141. Refer to *ni.com/calibration* for more information about calibration solutions.

Please review and become familiar with the entire procedure before beginning the calibration process.

Contents

Verification

The performance verification procedures assume that adequate traceable uncertainties are available for the calibration references.

Related Information

Reverification on page 18
Repeat the *Verification* section to determine the as-left status of the device.

Required Software

Calibrating the NI 4141 requires you to install the following software on the calibration system:

- NI-DCPower. The NI 4141 was first supported in NI-DCPower 1.7.5.
- Supported application development environment (ADE)—LabVIEW or LabWindows™/CVI™
- Supported operating system—Windows

You can download all required software from *ni.com/downloads*.

Related Documentation

You might find the following documents helpful as you perform the calibration procedure:

- *NI DC Power Supplies and SMUs Getting Started Guide*
- *NI DC Power Supplies and SMUs Help*
- *NI PXIe-4141 Specifications*
- *NI-DCPower Readme*

Visit *ni.com/manuals* for the latest versions of these documents.

Password

The default password for password-protected operations is `NI`.

Calibration Interval

Recommended calibration interval	1 year

Test Equipment

The following table lists the equipment NI recommends for the performance verification and adjustment procedures. If the recommended equipment is not available, select a substitute using the minimum requirements listed in the table.

Table 1. Required Equipment for Calibration

Required Equipment	Recommended Model(s)	Where Used	Minimum Specifications
Digital multimeter (DMM)	Keysight 3458A[1]	All parameters	Voltage: <±26 ppm accuracy and <1 µV resolution Current: <±100 ppm accuracy and <5 pA resolution
Two 50 Ω resistors	Vishay PTF5650R000BZEK	Voltage remote sense	0.1% tolerance, 1/8 W
Two 10 Ω resistors	Vishay CMF5510R000BEEK	Current remote sense	0.1% tolerance, 1/4 W
Two 100 Ω resistors	Vishay PTF65100R00BYEK	Current remote sense	0.1% tolerance, 1/4 W
Two 1 kΩ resistors	Vishay PTF651K0000BYEK	Voltage and current remote sense	0.1% tolerance, 1/4 W
Two 10 kΩ resistors	Vishay PTF6510K000BYEK	Current remote sense	0.1% tolerance, 1/4 W
Two 100 kΩ resistors	Vishay PTF65100K00BYEK	Current remote sense	0.1% tolerance, 1/4 W

Test Conditions

The following setup and environmental conditions are required to ensure the NI 4141 meets published specifications:

- Keep cabling as short as possible. Long cables act as antennas, picking up extra noise that can affect measurements.
- Verify that all connections to the NI 4141, including front panel connections and screws, are secure.
- Ensure that the PXI chassis fan speed is set to HIGH, that the fan filters, if present, are clean, and that the empty slots contain filler panels. For more information about cooling,

[1] To take measurements in the 10 µA range with the Keysight 3458A, you must send your device to the Keysight Primary Standards Lab for a special calibration to verify the 10 µA, 1 µA, and 100 nA ranges.

refer to the *Maintain Forced-Air Cooling Note to Users* document available at *ni.com/manuals*.

- Allow a warm-up time of at least 30 minutes after the chassis is powered on and NI-DCPower is loaded and recognizes the NI 4141. The warm-up time ensures that the NI 4141 and test instrumentation are at a stable operating temperature.
- Use shielded copper wire for all cable connections to the module. Use twisted-pair wire to eliminate noise and thermal offsets.
- To ensure the system has had adequate time to settle, wait one second after requesting a new current or voltage or after changing a load before taking a measurement.
- Keep relative humidity between 10% and 70%, noncondensing.
- Recalculate the test limits if they differ from the newest device specifications. Test limits in this document are based on the July 2013 edition of the *NI PXIe-4141 Specifications*.
- When making measurements, configure the following aperture time-related settings:
  - Set the **niDCPower Aperture Time** property or `NIDCPOWER_ATTR_APERTURE_TIME` attribute to 2 power-line cycles (PLCs) on the module.
  - Set the **niDCPower Aperture Time Units** property or `NIDCPOWER_ATTR_APERTURE_TIME_UNITS` to power line cycles.
  - Set the **niDCPower Configure Power Line Frequency** property or the `NIDCPOWER_ATTR_POWER_LINE_FREQUENCY` attribute to either 50 or 60 depending on the frequency of the AC power line in your location.
- Do not use the NI-DCPower Soft Front Panel (SFP) to request test points for any adjustment functions because you cannot set aperture time using the SFP.
- Ensure that properties or attributes for the module that are not specified in calibration procedures are set to their default values.
- When making measurements, configure any specified digital multimeters (DMMs) with the best available levels and limits for each specified test point.
- Disconnect any input signals and perform ACAL ALL function on Keysight 3458A every 24 hours or when the multimeter's temperature changes by ±1 °C from when it was last externally calibrated or from the last autocal. Use the TEMP? command for the current internal temperature and compare it to the calibration temperature from executing the command CAL? 59 for DCV and CAL? 60 for OHMS.
- Configure Keysight 3458A to 7 ½ digits of resolution and 10 NPLC.

Temperature conditions specific to verification procedures:

- Maintain an ambient temperature of 23 °C ±5 °C. Maintain an internal device temperature range of T_{cal} ±1 °C.[2]

[2] T_{cal} is the internal device temperature recorded by the NI 4141 at the completion of the last self-calibration. Call the niDCPower Get Self Cal Last Temp VI to query T_{cal} from the NI 4141.

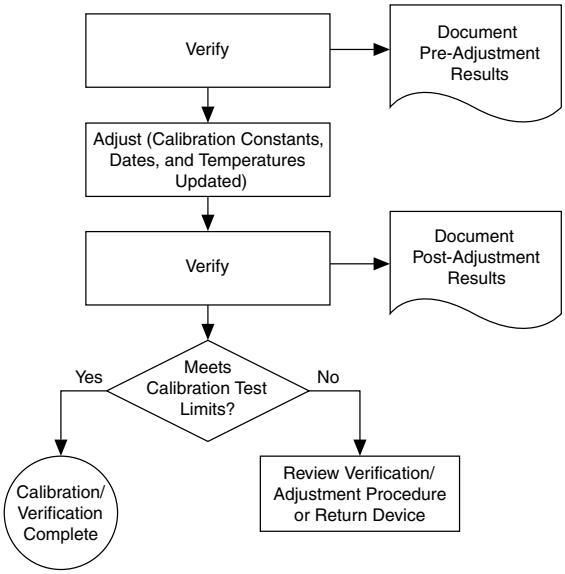
Temperature conditions specific to adjustment procedures:

- Maintain an ambient temperature of 23 °C ±1 °C. The NI 4141 internal temperature is greater than the ambient temperature.

Calibration Overview

Calibration includes the steps shown in the following figure.

Figure 1. Calibration Overview



1. Initial Setup—Install the NI 4141 and configure it in Measurement & Automation Explorer (MAX) .
2. Verification—Verify the existing operation of the NI 4141.

   This step confirms whether the device is operating within the published specifications prior to adjustment.
3. Adjustment—Adjust the calibration constants of the NI 4141.
4. Reverification—Repeat the Verification procedure to ensure that the device is operating within the published specifications after adjustment.

Self-Calibrating

Complete the following steps to self-calibrate the device.

1. Disconnect or disable all connections to the device.
2. Ensure the device had 30 minutes to warm up with the PXI chassis fans set to HIGH.
3. Initialize an NI-DCPower session.
4. Call the self-calibration function.

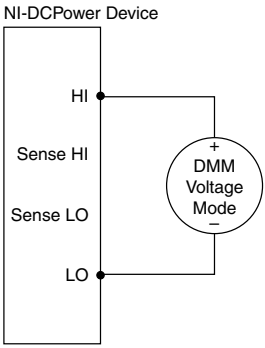
5. Close the NI-DCPower session.

Voltage Output and Measurement

Connecting and Configuring Equipment for Voltage Verification

1. Make the necessary connections for this procedure, as shown in the following figure:

Figure 2. Voltage Verification or Adjustment Connection Diagram



2. Set the **niDCPower Output Function** property or `NIDCPOWER_OUTPUT_FUNCTION` attribute to DC Voltage for the NI 4141.

Verifying Voltage Output and Measurement

Compare a set of voltages measured by the external DMM to both a set of voltage test points requested by the NI 4141 and to the measured voltages reported by the NI 4141.

Refer to the following table as you complete the following steps.

Table 2. Voltage Output and Measurement Verification

Level Range	Limit Range and Limit	Test Point	DMM Range	As-Found Output Test Limit (% of Voltage + Offset)	As-Found Measurement Test Limit (% of Voltage + Offset)
10 V	1 mA	-10 V	10 V	0.013% + 150 µV	0.013% + 150 µV
		-7.5 V	10 V		
		5 V	10 V		
		-2.5 V	10 V		
		0 V	100 mV		
		2.5 V	10 V		
		5 V	10 V		
		7.5 V	10 V		
		10 V	10 V		

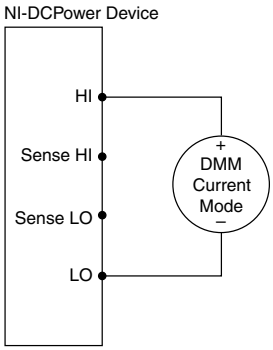
1. Set the first specified level range, limit range, and limit on the NI 4141.
2. Set the level on the NI 4141 to the first specified test point.
3. Take a voltage measurement using the DMM, and take a voltage measurement using the NI 4141.
4. Record the values from the previous step.
5. Calculate the lower and upper voltage output test limits using the following formula: *Voltage Output Test Limits = Test Point* ± (|*Test Point*| × *% of Voltage* + *Offset*)
6. Verify that the recorded DMM value falls within the test limits.
7. Calculate the lower and upper voltage measurement test limits using the following formula: *Voltage Measurement Test Limits = DMM Measured Voltage* ± (| *DMM Measured Voltage*| × *% of Voltage* + *Offset*). Record the test limits.
8. Verify that the recorded NI 4141 value falls within the test limits.
9. If more than one test point per level range is specified, repeat the previous steps for each test point, from setting the level to the test point on the NI 4141 up to this step.
10. If more than one level range is specified, repeat the previous steps using the values specified in each level range.

Current Output and Measurement

Connecting and Configuring Equipment for Current Verification

1. Make the necessary connections for this procedure, as shown in the following figure:

Figure 3. Current Verification or Adjustment Connection Diagram



2. Set the **niDCPower Output Function** property or `NIDCPOWER_OUTPUT_FUNCTION` attribute to DC Current for the NI 4141.

Verifying Current Output and Measurement

Compare a set of currents measured by the external DMM to both a set of current test points requested by the NI 4141 and to the measured currents reported by the NI 4141.

Refer to the following table as you complete the following steps.

Table 3. Current Output and Measurement Verification

Level Range	Limit Range and Limit	Test Point	DMM Range	As-Found Output Test Limit (% of Current + Offset)	As-Found Measurement Test Limit (% of Current + Offset)
10 µA	10 V	-10 µA	10 µA	0.03% + 300 pA	0.03% + 300 pA
		0 µA	1 µA		
		10 µA	10 µA		
100 µA	10 V	-100 µA	100 µA	0.03% + 3.0 nA	0.03% + 3.0 nA
		0 µA	1 µA		
		100 µA	100 µA		

Table 3. Current Output and Measurement Verification (Continued)

Level Range	Limit Range and Limit	Test Point	DMM Range	As-Found Output Test Limit (% of Current + Offset)	As-Found Measurement Test Limit (% of Current + Offset)
1 mA	10 V	-1 mA	1 mA	0.03% + 30 nA	0.03% + 30 nA
		-750 µA	1 mA		
		-500 µA	1 mA		
		-250 µA	1 mA		
		0 mA	1 µA		
		250 µA	1 mA		
		500 µA	1 mA		
		750 µA	1 mA		
		1 mA	1 mA		
10 mA	10 V	-10 mA	10 mA	0.03% + 300 nA	0.03% + 300 nA
		0 mA	10 µA		
		10 mA	10 mA		
100 mA	10 V	-100 mA	100 mA	0.03% + 3.0 µA	0.03% + 3.0 µA
		0 mA	100 µA		
		100 mA	100 mA		

1. Set the first specified level range, limit range, and limit on the NI 4141.
2. Set the level on the NI 4141 to the first specified test point.
3. Take a current measurement using the DMM, and take a current measurement using the NI 4141.
4. Record the values from the previous step.
5. Calculate the lower and upper current output test limits using the following formula: *Current Output Test Limits = Test Point* ± (|*Test Point*| × *% of Current + Offset*)
6. Verify that the recorded DMM value falls within the test limits.
7. Calculate the lower and upper current measurement test limits using the following formula: *Current Measurement Test Limits = DMM Measured Current* ± (|*DMM Measured Current*| × *% of Current + Offset*).
8. Verify that the recorded NI 4141 value falls within the test limits.

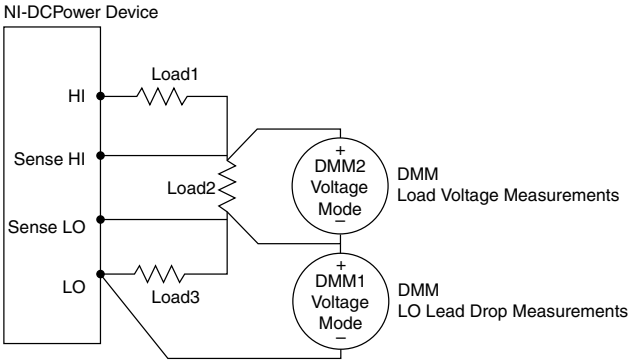
9. If more than one test point per level range is specified, repeat the previous steps for each test point, from setting the level to the test point on the NI 4141 up to this step. For zero current test points, disconnect all external equipment from the I/O connector on the NI 4141 and take a current measurement solely with the NI 4141, in order to ensure that the output current is zero. In calculations for zero current test points, substitute 0 A for the *DMM Measured Current*.
10. If more than one level range is specified, repeat the previous steps using the values specified in each level range.

Remote Sense

Connecting and Configuring Equipment for Voltage Remote Sense Accuracy Verification

1. Make the necessary connections for this procedure, as shown in the following figure:

Figure 4. Voltage Remote Sense Output Verification Connection Diagram



2. Set the **niDCPower Sense** property or `NIDCPOWER_ATTR_SENSE` attribute to Remote.
3. Set the **niDCPower Output Function** property or `NIDCPOWER_OUTPUT_FUNCTION` attribute to DC Voltage for the NI 4141.

Verifying Voltage Remote Sense Accuracy

Use the NI 4141 in constant voltage mode with a test circuit to simulate the voltage drop between the device and a load.

Complete this procedure only after successfully completing all previous Verification procedures.

Refer to the following table as you complete the following steps.

Table 4. Voltage Remote Sense Output Verification

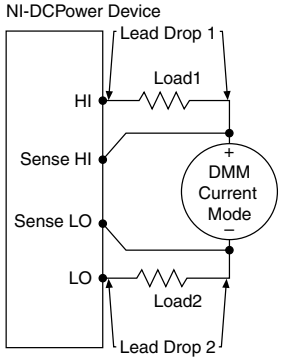
Level Range	Limit Range and Limit	Test Point	DMM Range	$Load_1$	$Load_2$	$Load_3$
10 V	100 mA	10 V	10 V	50 Ω	1 kΩ	50 Ω

1. Set the first specified level range, limit range, and limit on the NI 4141.
2. Set the level on the NI 4141 to the first specified test point.
3. Measure the LO lead drop with *DMM1* from the negative terminal of the device to the negative side of *Load2*. Record the measurement as *Lead Drop*.
4. Measure the load voltage with *DMM2* across *Load2* where the sense leads connect. Record the measurement as *Load Voltage*.
5. Calculate the upper and lower voltage remote sense test limits using the following equation: *Voltage Remote Sense Test Limit* = 10 V ± (0.00145 V + *LO Lead Drop* × 0.001). Record the test limits.
6. Verify the *Load Voltage* measurement falls within the voltage remote sense test limits.
7. If more than one test point per level range is specified, repeat the previous steps for each test point, from setting the level to the test point on the NI 4141 up to this step.
8. If more than one level range is specified, repeat the previous steps using the values specified in each level range.

Connecting and Configuring Equipment to Verify Current Remote Sense Accuracy

1. Refer to the following figure to make the necessary connections to verify current remote sense accuracy.

Figure 5. Current Remote Sense Output Verification Connection Diagram



2. Set the **niDCPower Sense** property or `NIDCPOWER_ATTR_SENSE` attribute to Remote.
3. Set the **niDCPower Output Function** property or `NIDCPOWER_OUTPUT_FUNCTION` attribute to DC Current for the NI 4141.

Verifying Current Remote Sense Accuracy

Use the NI 4141 in constant current mode with a test circuit to simulate the voltage drop between the device and a load.

Measure all of the specified resistors using the DMM before you connect equipment. Record the values.

Refer to the following table as you complete the following steps.

Table 5. Current Remote Sense Output Verification

Level Range	Limit Range and Limit	Test Point	DMM Range	$Load_1$	$Load_2$	Base Limit
10 µA	10 V	-10 µA	10 µA	100 kΩ	100 kΩ	3.3 nA
		0 µA	10 µA			
		10 µA	10 µA			
100 µA	10 V	-100 µA	100 µA	10 kΩ	10 kΩ	33 nA
		0 µA	100 µA			
		100 µA	100 µA			
1 mA	10 V	-1 mA	1 mA	1 kΩ	1 kΩ	330 nA
		0 mA	1 mA			
		1 mA	1 mA			
10 mA	10 V	-10 mA	10 mA	100 Ω	100 Ω	3.3 µA
		0 mA	10 mA			
		10 mA	10 mA			
100 mA	10 V	-100 mA	100 mA	10 Ω	10 Ω	33 µA
		0 mA	100 mA			
		100 mA	100 mA			

1. Set the first specified level range, limit range, and limit on the NI 4141.
2. Set the level on the NI 4141 to the first specified test point.
3. Calculate the total lead drop using the following steps.
   a) Take a current measurement using the DMM. Record the value.
   b) Calculate the voltage across *Load1* using the following formula: *DMM Measured Current * Load1*. Record as *Lead Drop 1*.
   c) Calculate the voltage across *Load2* using the following formula: *DMM Measured Current * Load2*. Record as *Lead Drop 2*.

d) Calculate the total lead drop using the following equation: *Total Lead Drop = Lead Drop 1 + Lead Drop 2*. Record the value.

4. Calculate the upper and lower current remote sense test limits using the following equation: *Current Remote Sense Test Limit = Test Point* ± (*Base Limit* + (*Total Lead Drop* × 0.02% of *Level Range*). Record the test limits.
5. Verify the recorded DMM current falls within the test limits.
6. If more than one test point per level range is specified, repeat the previous steps for each test point, from setting the level to the test point on the NI 4141 up to this step.
7. If more than one level range is specified, repeat the previous steps using the values specified in each level range.

Adjustment

This section describes the steps needed to adjust the NI 4141 to meet published specifications.

Related Information

For information on VIs and functions used in adjustment, refer to the NI DC Power and SMUs Help

Adjusted Specifications

Adjustment corrects the following specifications for the device:

- Voltage programming accuracy
- Current programming accuracy
- Voltage measurement accuracy
- Current measurement accuracy

Following the adjustment procedure automatically updates the calibration date and temperature on the device.

Note You do not need to separately adjust both measurement and output. The architecture of the NI 4141 ensures that if measurement is accurate, then output is as well, and vice versa.

Self-Calibrating

Complete the following steps to self-calibrate the device.

1. Disconnect or disable all connections to the device.
2. Ensure the device had 30 minutes to warm up with the PXI chassis fans set to HIGH.
3. Initialize an NI-DCPower session.
4. Call the self-calibration function.
5. Close the NI-DCPower session.

Initiating the Adjustment Session

Initiate an external calibration session (a special type of NI-DCPower session) by calling the niDCPower Initialize External Calibration VI or `niDCPower_InitExtCal` function.

(Optional) You can close the session and commit the new constants to hardware after you complete each adjustment procedure.

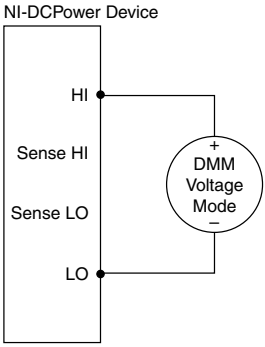
Related Information

Closing the Adjustment Session on page 17

Connecting and Configuring Equipment for Voltage Adjustment

1. Make the necessary connections for this procedure, as shown in the following figure:

Figure 6. Voltage Verification or Adjustment Connection Diagram



2. Set the **niDCPower Output Function** property or `NIDCPOWER_OUTPUT_FUNCTION` attribute to DC Voltage for the NI 4141.

Adjusting Voltage Measurement

Compare a set of measured voltages reported by the NI 4141 to the voltages measured by a DMM. You do not need to separately verify both measurement and output. The architecture of the NI 4141 ensures that if measurement is accurate, then output is as well, and vice versa.

Refer to the following table as you complete the following steps.

Table 6. Voltage Measurement Adjustment

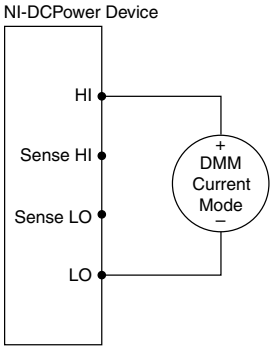
Level Range	Limit Range and Limit	Test Point
10 V	1 mA	10 V
		-10 V

1. Set the first specified level range, limit range, and limit on the NI 4141.
2. Set the level on the NI 4141 to the first specified test point.
3. Take a voltage measurement using the DMM, and take a voltage measurement using the NI 4141.
4. Store the values from the previous step as inputs for the niDCPower Cal Adjust VI or function called in the following steps.
5. If more than one test point per level range is specified, repeat the previous steps for each test point, from setting the level to the test point on the NI 4141 up to this step.
6. If more than one level range is specified, repeat the previous steps using the values specified in each level range.
7. Update the measurement calibration constants by configuring and calling the niDCPower Cal Adjust Voltage Measurement VI or `niDCPower_CalAdjustVoltageMeasurement` function.
   a) Input the DMM measurements as the **measured outputs**.
   b) Input the NI 4141 measurements as the **reported outputs**.
   c) Input the specified level range as the **range**.

Connecting and Configuring Equipment for Current Adjustment

1. Make the necessary connections for this procedure, as shown in the following figure:

Figure 7. Current Verification or Adjustment Connection Diagram



2. Set the **niDCPower Output Function** property or `NIDCPOWER_OUTPUT_FUNCTION` attribute to DC Current for the NI 4141.

Adjusting Current Measurement

Compare a set of measured currents reported by the NI 4141 to the currents measured by an external DMM.

Refer to the following table as you complete the following steps.

Table 7. Current Measurement Adjustment

Level Range	Limit Range and Limit	Test Point
10 µA	10 V	10 µA
		-10 µA
100 µA	10 V	100 µA
		-100 µA
1 mA	10 V	1 mA
		-1 mA
10 mA	10 V	10 mA
		-10 mA
100 mA	10 V	100 mA
		-100 mA

1. Set the first specified level range, limit range, and limit on the NI 4141.
2. Set the level on the NI 4141 to the first specified test point.
3. Take a current measurement using the DMM, and take a current measurement using the NI 4141.
4. Store the values from the previous step as inputs for the niDCPower Cal Adjust VI or function called in the following steps.
5. If more than one test point per level range is specified, repeat the previous steps for each test point, from setting the level to the test point on the NI 4141 up to this step. For zero current test points, disconnect all external equipment from the I/O connector on the NI 4141 and take a current measurement solely with the NI 4141, in order to ensure that the output current is zero. In calculations for zero current test points, substitute 0 A for the *DMM Measured Current*.
6. If more than one level range is specified, repeat the previous steps using the values specified in each level range.
7. Update the measurement calibration constants by configuring and calling the VI niDCPower Cal Adjust Current Measurement or `niDCPower_CalAdjustCurrentMeasurement` function.
   a) Input the DMM measurements as the **measured outputs**.

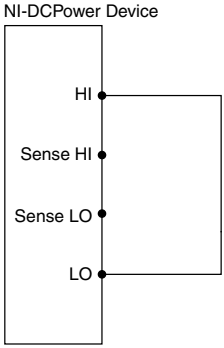
b) Input the NI 4141 measurements as the **reported outputs**.

c) Input the specified level range as the **range**.

Connecting and Configuring Equipment to Adjust Residual Offset Voltage

1. Make the necessary connections for this procedure, as shown in the following figure:

Figure 8. Residual Voltage Adjustment Diagram



2. Set the **niDCPower Output Function** property or `NIDCPOWER_OUTPUT_FUNCTION` attribute to DC Voltage for the NI 4141.

Adjusting Residual Voltage Offset

Eliminate residual offset voltage at 0 V by configuring and calling the niDCPower Cal Adjust Residual Voltage Offset VI or `niDCPower_CalAdjustResidualVoltageOffset` function.

Adjusting Residual Current Offset

1. Disconnect all equipment from the output of the NI 4141.
2. Eliminate offset current at 0 A by configuring and calling the niDCPower Cal Adjust Residual Current Offset VI or `niDCPower_CalAdjustResidualCurrentOffset` function.

Closing the Adjustment Session

Close the session and commit the new constants to hardware by calling the niDCPower Close External Calibration VI or `niDCPower_CloseExtCal` function and specifying Commit as the **calibration close action**.

Alternative to Adjustment Procedures

If your device passes all verification procedures successfully and you want to skip updating the calibration constants, you can update solely the calibration date by completing the following steps.

Note NI recommends following all adjustment procedures in order to update the calibration constants and renew the device calibration interval.

1. Call one of the following:
   - niDCPower Initialize External Calibration VI
   - `niDCPower_InitExtCal` function
2. Call one of the following, specifying Commit in **calibration close action**:
   - niDCPower Close External Calibration VI
   - `niDCPower_CloseExtCal` function

Reverification

Repeat the *Verification* section to determine the as-left status of the device.

Note If no as-left test limits are specified in a procedure, reuse the as-found test limits.

Note If any test fails reverification after performing an adjustment, verify that you have met the *Test Conditions* before returning your device to NI. Refer to the *Worldwide Support and Services* section for information about support resources or service requests.

Related Information

Test Conditions on page 3

Verification on page 2

Setting the Calibration Due Date

Use either Measurement Automation Explorer (MAX) or NI System Configuration API to set a calibration due date for the device or to clear the calibration due date. NI suggests a minimum calibration due date of the date of external calibration plus the external calibration interval for the device.

1. In MAX, navigate to the External Calibration section of the Settings tab to update the Calibration Due Date entry.
2. Alternatively, use the Update Calibration VI in the NI System Configuration API to set the calibration due date for either a specific date or an interval in months.

Revision History

Revision	Edition Date	Section	Changes
375060B-01	November 2020	Required Equipment for Calibration	The recommended DMM was changed from the Agilent 3458A to the Keysight 3458A.
		Voltage Output and Measurement, Current Output and Measurement, Remote Sense	DMM range was added to all verification tables.

NI Services

Visit *ni.com/support* to find support resources including documentation, downloads, and troubleshooting and application development self-help such as tutorials and examples.

Visit *ni.com/services* to learn about NI service offerings such as calibration options, repair, and replacement.

Visit *ni.com/register* to register your NI product. Product registration facilitates technical support and ensures that you receive important information updates from NI.

NI corporate headquarters is located at 11500 N Mopac Expwy, Austin, TX, 78759-3504.

375060B-01 October 14, 2020