

CALIBRATION PROCEDURE

NI PXI-4130

Programmable Source Measure Unit

This document contains the verification and adjustment procedures for the National Instruments PXI-4130 (NI 4130) programmable, high-power source measure unit (SMU). For more information about calibration solutions, visit ni.com/calibration. Please review and become familiar with the entire procedure before beginning the calibration process.

Contents

Software.....	2
Related Documentation	3
Password.....	3
Calibration Interval.....	3
Test Equipment.....	4
Test Conditions.....	4
Calibration Procedures	5
Initial Setup.....	5
Verification.....	6
Verifying Voltage Programming Accuracy.....	8
Verifying Voltage Measurement Accuracy.....	10
Verifying Current Programming Accuracy	11
Verifying Current Measurement Accuracy	16
Verifying Load Regulation.....	19
Voltage Load Regulation.....	20
Current Load Regulation	22
Verifying Line Regulation.....	25
Voltage Line Regulation.....	25
Verifying Remote Sense Output.....	31
Adjustment.....	33
Considerations	33
Adjusting Voltage Programming Accuracy	34
Adjusting Voltage Measurement Accuracy.....	36
Adjusting Current Programming Accuracy.....	37
Adjusting Current Measurement Accuracy	43
Revision History	45
Worldwide Support and Services	45



Software

To calibrate the NI 4130, you must install the NI-DCPower instrument driver version 1.2 or later on the Windows calibration system. You can download the latest version of NI-DCPower at ni.com/downloads. NI-DCPower supports LabVIEW and LabWindows™/CVI™. When you install NI-DCPower, you need to install only the application software that you intend to use.

LabVIEW support is in the `nidcpower.llb` file, and all calibration VIs are accessible from the NI-DCPower Calibration palette. For LabWindows/CVI users, the `nidcpower.fp` provides access to the calibration functions. Refer to Table 1 for file locations.

C function calls are valid for any compiler capable of calling a 32-bit or 64-bit DLL. Many of the functions use constants defined in the `nidcpower.h` file. To use these constants in C, you must include `nidcpower.h` in the calibration program.

For more information about calibration VIs and functions, refer to the *Programming with NI-DCPower* book in the *NI DC Power Supplies and SMUs Help*. The *NI DC Power Supplies and SMUs Help* is accessible at **Start»All Programs»National Instruments»NI-DCPower»Documentation»NI DC Power Supplies and SMUs Help**.

Table 1. Calibration File Locations (NI-DCPower 1.2 or Later)

File Name and Location	Description
IVI\Bin\nidcpower_32.dll	NI-DCPower driver containing the entire NI-DCPower API, including calibration functions.
IVI\Bin\nidcpower_64.dll	NI-DCPower driver containing the entire NI-DCPower API, including calibration functions.
IVI\Lib\msc\nidcpower.lib	NI-DCPower library for Microsoft C containing the entire NI-DCPower API, including calibration functions.
<LabVIEW>\instr.lib\niDCPower\niDCPower.llb	LabVIEW VI library containing VIs for calling the NI-DCPower calibration API. You can access calibration functions from the NI-DCPower calibration section of the LabVIEW function palette.
IVI\Drivers\niDCPower\nidcpower.fp	LabWindows/CVI function panel file that includes calibration function prototypes and help on using NI-DCPower in the LabWindows/CVI environment.
IVI\Include\nidcpower.h	NI-DCPower header file, which you must include in any C program accessing calibration functions. This file includes the entire NI-DCPower API, including calibration functions.

Related Documentation

Consult the following documents for information about the NI 4130, NI-DCPower, and your application software. All documents install with the software and are available at ni.com/manuals.



NI DC Power Supplies and SMUs Getting Started Guide

Contains instructions for NI-DCPower installation, hardware installation, and hardware programming.



NI PXI-4130 Specifications

Contains NI PXI-4130 specifications and calibration interval.



NI-DCPower Readme

Contains operating system and application software support in NI-DCPower.



NI DC Power Supplies and SMUs Help

Contains detailed information about the NI PXI-4130.



LabVIEW Help

Contains LabVIEW programming concepts and reference information about NI-DCPower VIs and functions.



NI-DCPower C Reference Help

Contains reference information for NI-DCPower C functions and NI-DCPower C properties.

Password

The default calibration password is **NI**.

Calibration Interval

National Instruments recommends that you perform a complete calibration for the NI 4130 at least once a year. You can shorten this calibration interval based on the accuracy demands of your application. Refer to [Worldwide Support and Services](#) for more information.

Test Equipment

Table 2 lists the equipment required to calibrate the NI 4130. If you do not have the recommended equipment, select a substitute calibration standard using the specifications listed in Table 2.

Table 2. Equipment Specifications for NI 4130 Calibration

Equipment	Recommended Equipment	Specifications
Digital multimeter (DMM)	NI PXI-4071 NI PXIe-4081	Voltage: > ±50 ppm accuracy, > 30 µV resolution Current: > ±0.04% accuracy, > 1 µA resolution
Variable power supply	Xantrex HPD 30-10	Variable between 11 V and 15.5 V, 5 A
External load	Clarostat 240C IET HPRS-F-6-1	Power resistor decade box with a range of 2 Ω to 48,000 Ω and an accuracy of ±10%
Resistors	—	Two 50 Ω, 0.25 Ω ±10% resistors, and one 1 kΩ, 0.25 Ω ±10% resistor
External calibrator	Fluke 5700A/5720A/5730A	—
Auxiliary power supply	NI APS-4100	11 V to 15.5 V, 5 A
Twisted pair, shielded cabling wire	Belden 83319E 009100	18 AWG to 22 AWG

Test Conditions

Follow these guidelines to optimize the connections and the environment during calibration:

- Keep connections to the device as short as possible. Long cables and wires act as antennas, picking up extra noise that can affect measurements.
- Verify that all connections to the device, including front panel connections, are secure.
- Ensure that the PXI chassis fan speed is set to HI, that the fan filters are clean, and that the empty slots contain filler panels. For more information, refer to the *Maintain Forced-Air Cooling Note to Users* document available at ni.com/manuals.
- Keep relative humidity between 10% and 90%, noncondensing.
- Ensure that the ambient temperature is 23 ±5 °C.

- Allow a warm-up time of at least 30 minutes after you load the NI-DCPower driver. Unless manually disabled, the NI-DCPower driver automatically loads with the operating system and enables the device. The warm-up time ensures that the measurement circuitry of the NI 4130 is at a stable operating temperature.
- Use shielded copper wire for all cable connections to the device. Use twisted-pair wire to eliminate noise and thermal offsets.
- Plug the chassis and the instrument standard into the same power strip to avoid ground loops.

Calibration Procedures

The calibration process includes the following procedures:

1. **Initial Setup**—Install the device and configure it in Measurement & Automation Explorer (MAX).
2. **Verification**—Verify the existing operation of the device. This procedure confirms whether the device is operating within its specified range prior to calibration.
3. **Adjustment**—Perform an external adjustment of the device that adjusts the calibration constants with respect to a known voltage source or current source. The adjustment procedure automatically stores the calibration date on the EEPROM to allow traceability.
4. **Reverification**—Repeat the verification procedure to ensure that the device is operating within its specifications after adjustment.

These procedures are described in more detail in the following sections.



Note The complete external calibration procedure consists of verifying the performance of the SMU, adjusting the calibration constants, and verifying performance again after the adjustments. In some cases, a complete calibration procedure may not be required. Refer to [Worldwide Support and Services](#) for more information.

Initial Setup

Refer to the *NI DC Power Supplies and SMUs Getting Started Guide* for information about how to install the software and hardware and how to configure the device in MAX.

Verification

This section provides instructions for verifying the NI 4130 specifications.

Verification consists of generating and measuring a series of outputs using the NI 4130, verifying the accuracy with the DMM, and comparing the results to the calibration As Found/As Left Limits. If the results fall within the As Found/As Left Limits, the NI 4130 meets its published specifications, and adjustment is optional. If the results fall outside of the As Found/As Left Limits, you must adjust the NI 4130.

Verification tests the following NI 4130 specifications:

- Voltage programming accuracy
- Voltage measurement accuracy
- Current programming accuracy
- Current measurement accuracy
- Voltage load regulation
- Current load regulation
- Voltage line regulation
- Current line regulation
- Remote sense output

Tables 3 and 4 list configuration information for the calibration equipment required for verification.

Table 3. Calibration Equipment Configuration for Voltage Programming and Measurement Verification/Adjustment

NI 4130		DMM*		
Channel(s)	Range	Function	Range†	Input Impedance†
0	6 V	DC Voltage	10 V	10 GΩ
1	6 V		10 V	10 GΩ
	20 V		100 V	10 MΩ
* Use the highest resolution available on the DMM. The DMM should have a minimum of 6.5 digit resolution.				
† Assumes an NI 4071 DMM. For all other DMMs, use the range and input impedance closest to the values listed in this table.				

Table 4. Calibration Equipment Configuration for Current Programming and Measurement Verification/Adjustment

NI 4130		DMM*				Calibrator Resistance
Channel	Range	Function	Range	Input Impedance†	Resolution in Digits	
0	1 A	DC Current	1 A	N/A	6.5	N/A
1	200 μ A	DC Voltage	10 V	10 G Ω	7.5	10 k Ω
	2 mA	DC Voltage	10 V	10 G Ω	7.5	1 k Ω
	20 mA	DC Voltage	10 V	10 G Ω	7.5	100 Ω
	200 mA	DC Voltage	10 V	10 G Ω	7.5	10 Ω
	2 A	DC Current	3 A	N/A	6.5	N/A
* Use the highest resolution available on the DMM. † Assumes an NI 4071 DMM. For all other DMMs, use the range and input impedance closest to the values listed in this table.						

Verification of the NI 4130 is complete only after you successfully complete all tests in this section.



Note If verification fails post-adjustment, confirm that you have met the required *Test Conditions* before you return the NI 4130 to NI for repair.

Verifying Voltage Programming Accuracy

To verify the voltage programming accuracy, compare a set of requested voltage test points to measurements of the actual voltage by the DMM. Refer to the following figure for the necessary connections.

Figure 1. Voltage Accuracy Verification and Adjustment Setup for the NI 4130

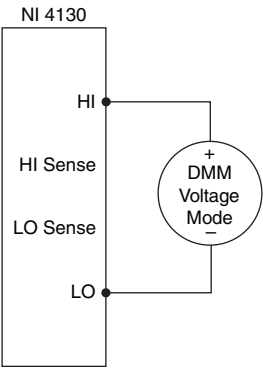


Table 5 lists the voltage test points for each channel that you must request from the NI 4130 and measure with the DMM to complete verification. Take voltage measurements using the DMM at each test point, and compare the result to the programmed voltage value from the *Output* column of Table 5 to calculate the output error. Compare the output error to the *As Found/As Left Limit* for the iteration of channel *x* in Table 5. If the output error is outside the *As Found/As Left Limit*, adjust the NI 4130.

To ensure that the system has had adequate time to settle, wait one second after requesting a new voltage before taking a measurement with the DMM.

When you have verified all iterations per channel, this part of the verification is complete.

Table 5. NI 4130 Output Parameters and As Found/As Left Limits for Voltage Programming Accuracy Verification

Channel	Voltage Level Range (V)	Iteration	Output (V)	As Found / As Left Limit (mV)
0	6	1	0	±4.00
		2	1.5	±4.75
		3	3	±5.50
		4	4.5	±6.25
		5	6	±7.00
1	6	1	0	±1.50
		2	1.5	±2.01
		3	3	±2.52
		4	4.5	±3.03
		5	6	±3.54
		6	-1.5	±2.01
		7	-3	±2.52
		8	-4.5	±3.03
		9	-6	±3.54
	20	1	0	±1.80
		2	5	±3.50
		3	10	±5.20
		4	15	±6.90
		5	20	±8.60
		6	-5	±3.50
		7	-10	±5.20
		8	-15	±6.90
		9	-20	±8.60

Verifying Voltage Measurement Accuracy

To verify the voltage measurement accuracy of the NI 4130, compare a set of measurements taken by the NI 4130 to measurements of the actual voltage at the output by a DMM. Refer to the following figure for the necessary connections.

Figure 2. Voltage Verification Connection Diagram

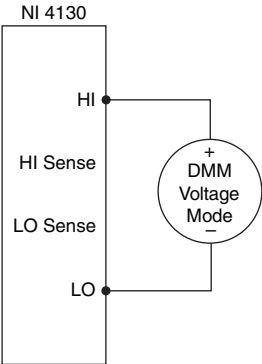


Table 6 lists the voltage test points that you must request for each channel and then measure with both the DMM and the NI 4130 to complete verification. Take voltage measurements using the DMM at each test point, and then take voltage measurements using the NI 4130 at each test point and compare the two values. Calculate the upper and lower As Found/As Left Limits using the gain and offset listed in the *As Found/As Left Limit* column for the iteration of channel x in Table 6. Table 6 lists tolerances instead of absolute limits because the As Found/As Left Limit is based on the output of the DMM and must be calculated by the user. Each limit is calculated by adding a percentage of the DMM measurement and an offset voltage. Verify that the difference between the NI 4130 measurement and the DMM measurement falls between the calculated limits. If the measurement error is outside the As Found/As Left Limit, adjust the NI 4130.

When taking measurements with the NI 4130, set the Samples to Average property to 300.

To ensure the system has had adequate time to settle, wait one second after requesting a new current before taking a measurement with the DMM. When you verify all iterations per channel, this part of the verification is complete.

Table 6. NI 4130 Output Parameters and As Found/As Left Limits for Voltage Measurement Accuracy Verification

Channel	Voltage Level Range (V)	Iteration	Output (V)	As Found/As Left Limit (V) (% of DMM Measurement + Offset)
0	6	1	0	$\pm (0.05\% + 4 \text{ mV})$
		2	1.5	
		3	3	
		4	4.5	
		5	6	
1	20	1	0	$\pm (0.03\% + 1.5 \text{ mV})$
		2	5	
		3	10	
		4	15	
		5	20	
		6	-5	
		7	-10	
		8	-15	
		9	-20	

Verifying Current Programming Accuracy

To verify current programming accuracy, compare a set of requested current test points to measurements of the actual current at the output by the DMM. Connect an NI APS-4100 auxiliary power supply for this verification procedure. Refer to Figure 3 and Figure 4 for the necessary connections.

The setup in Figure 3 measures the 200 μ A, 2 mA, 20 mA, and 200 mA current ranges of channel 1. The setup in Figure 4 measures the 1 A current range of channel 0 and the 2 A current range of channel 1.

Figure 3. Current Programming Accuracy Verification Setup for the 200 μ A, 2 mA, 20 mA, and 200 mA Current Ranges of Channel 1

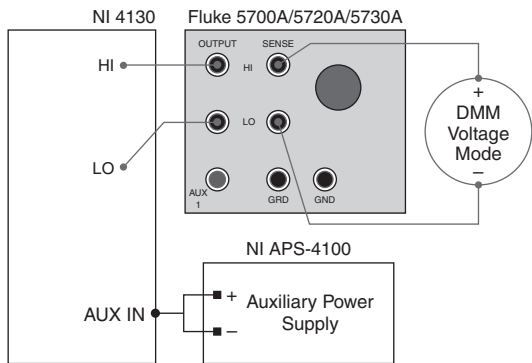


Figure 4. Current Programming Accuracy Verification Setup for the 1 A Current Range of Channel 0 and the 2 A Range of Channel 1

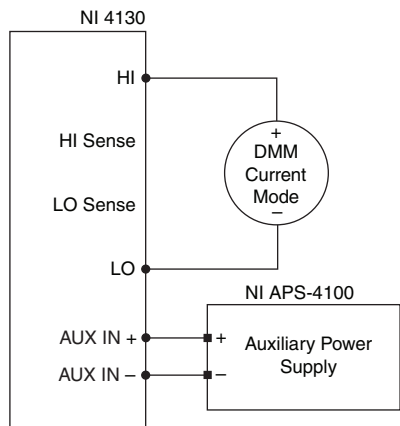


Table 7 lists the test points you must request from the NI 4130 in DC Voltage mode and measure with the DMM to complete verification. For each iteration, set the current limit of the NI 4130 to the value in the *Output* column of Table 7.

To ensure the system has had adequate time to settle, wait one second after requesting a new current limit before taking a measurement with the DMM.

When applicable, configure the Fluke 5700/5720A/5730A calibrator to the *Resistance* value for the corresponding channel and range in Table 4. Enable external sense (4-wire mode) on the

calibrator. Record the actual resistance value displayed by the calibrator. You should also configure the DMM to the settings in Table 4.

For the 200 μA , 2 mA, 20 mA, and 200 mA current ranges of channel 1, divide the voltage measurement you record from the DMM by the resistance measurement you record from the calibrator to calculate the output current. For the 1 A current range of channel 0 and the 2 A current range of channel 1, the DMM measures the output current directly. Subtract the *Output* value for the iteration of channel x in Table 7 from the output current calculated above to obtain the output error.

Compare the output error to the *As Found/As Left Limit* for the iteration of channel x in Table 7. If the output error is outside the *As Found/As Left Limit*, you must adjust the NI 4130.

Table 7. NI 4130 Output Parameters and As Found/As Left Limits for Current Programming Accuracy Verification

Channel(s)	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output (A)	As Found/As Left Limit
0	1 A	6 V	6 V	1	50 mA	± 4.08 mA
				2	350 mA	± 4.53 mA
				3	700 mA	± 5.05 mA
1	200 μA	20 V	20 V	1	4.00 μA	± 0.101 μA
				2	50.0 μA	± 0.115 μA
				3	0.10 mA	± 0.130 μA
				4	0.15 mA	± 0.145 μA
				5	0.20 mA	± 0.160 μA
			-20 V	6	4.00 μA	± 0.101 μA
				7	0.50 μA	± 0.115 μA
				8	0.10 mA	± 0.130 μA
				9	0.15 mA	± 0.145 μA
				10	0.20 mA	± 0.160 μA

Table 7. NI 4130 Output Parameters and As Found/As Left Limits for Current Programming Accuracy Verification (Continued)

Channel(s)	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output (A)	As Found/As Left Limit
1	2 mA	20 V	20 V	1	40.0 μA	±1.01 μA
				2	0.50 mA	±1.15 μA
				3	1.00 mA	±1.30 μA
				4	1.50 mA	±1.45 μA
				5	2.00 mA	±1.60 μA
			-20 V	6	40.0 μA	±1.01 μA
				7	0.50 mA	±1.15 μA
				8	1.00 mA	±1.30 μA
				9	1.50 mA	±1.45 μA
				10	2.00 mA	±1.60 μA
	20 mA	20 V	1	0.40 mA	±10.1 μA	
			2	5.00 mA	±11.5 μA	
			3	10.0 mA	±13.0 μA	
			4	15.0 mA	±14.5 μA	
1	20 mA	20 V	20 V	5	20.0 mA	±16.0 μA
				-20 V	6	0.40 mA
			7		5.00 mA	±11.5 μA
			8		10.0 mA	±13.0 μA
			9		15.0 mA	±14.5 μA
			10	20.0 mA	±16.0 μA	

Table 7. NI 4130 Output Parameters and As Found/As Left Limits for Current Programming Accuracy Verification (Continued)

Channel(s)	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output (A)	As Found/As Left Limit
1	200 mA	20 V	20 V	1	4.00 mA	± 0.101 mA
				2	50.0 mA	± 0.115 mA
				3	100 mA	± 0.130 mA
				4	150 mA	± 0.145 mA
				5	200 mA	± 0.160 mA
			-20 V	6	4.00 mA	± 0.101 mA
				7	50.0 mA	± 0.115 mA
				8	100 mA	± 0.130 mA
				9	150 mA	± 0.145 mA
				10	200 mA	± 0.160 mA
	2 A	20 V	20 V	1	40.0 mA	± 1.05 mA
				2	0.5 A	± 1.60 mA
				3	1.0 A	± 2.70 mA
				4	1.5 A	± 4.68 mA
				5	2.0 A	± 8.40 mA
			-20 V	6	40.0 mA	± 1.05 mA
				7	0.5 A	± 1.60 mA
				8	1.0 A	± 2.70 mA
				9	1.5 A	± 4.68 mA
				10	2.0 A	± 8.40 mA

Verifying Current Measurement Accuracy

To verify current measurement accuracy, compare a set of currents measured using an external DMM to the measured current reported by the NI 4130. Connect an NI APS-4100 auxiliary power supply for this verification procedure. Refer to Figure 3 and Figure 4 for the necessary connections.

Calculate the As Found/As Left Limit from the DMM measurement and the As Found/As Left Limit values in Table 8. Compare the difference between the DMM measurement and the NI 4130 measurement to the As Found/As Left Limit for the iteration of channel x in Table 8. If the output error is outside the As Found/As Left Limit, you must adjust the NI 4130.

Complete the following steps to verify the current measurement accuracy of the NI 4130. Complete this procedure for each channel iteration per supported range in Table 8.

If the *Voltage Level* in Table 8 for this iteration of channel x is 0, do *not* connect the DMM or the Fluke 5700A/5720A/5730A calibrator to the channel x output terminals of the NI 4130.

For *Output* values other than 0, connect the NI 4130 channel x to the DMM or to the Fluke 5700A/5720A/5730A calibrator, as illustrated in Figure 3 or Figure 4.

When applicable, configure the Fluke 5700/5720A/5730A calibrator to the *Resistance* value for the corresponding channel and iteration in Figure 4. Enable external sense (4-wire mode) on the calibrator and record the actual resistance value displayed by the calibrator.

Use the setup in Figure 3 for the 200 μ A, 2 mA, 20 mA, and 200 mA current ranges of channel 1. Use the setup in Figure 4 for the 1 A current range of channel 0 and the 2 A current range of channel 1.



Note Channel x represents the channel under test. Replace the variable x in the program with the actual channel name.

Configure the DMM using the configuration settings for channel x in Table 4. Table 8 lists the NI 4130 parameters you must set in DC Voltage mode for each current limit range to complete verification. Set the current limit to the value in the *Output* column of Table 8.

When taking measurements with the NI 4130, set the Samples to Average property to 300.

To ensure the system has had adequate time to settle, wait three seconds after requesting a new current limit before taking a measurement with the DMM.

Table 8. NI 4130 Output Parameters and As Found/As Left Limits for Current Measurement Accuracy Verification

Channel(s)	Current Limit Range	Voltage Level Range (V)	Voltage Level (V)	Iteration	Output	As Found/As Left Limit $\pm$ (% of reading + offset)
0	1 A	6	0	1	350 mA	0.15% + 4 mA ¹
			6	2	350 mA	
				3	700 mA	
1	200 μ A	20	0	1	50.0 μ A	0.03% + 0.02 μ A
			20	2	50.0 μ A	
				3	0.10 mA	
				4	0.150 mA	
				5	0.20 mA	
			-20	6	50.0 μ A	
				7	0.10 mA	
				8	0.15 mA	
				9	0.20 mA	
	2 mA	20	0	1	0.50 mA	0.03% + 0.2 μ A
			20	2	0.50 mA	
				3	1.00 mA	
				4	1.50 mA	
				5	2.00 mA	
			-20	6	0.50 mA	
				7	1.00 mA	
				8	1.50 mA	
				9	2.00 mA	

Table 8. NI 4130 Output Parameters and As Found/As Left Limits for Current Measurement Accuracy Verification (Continued)

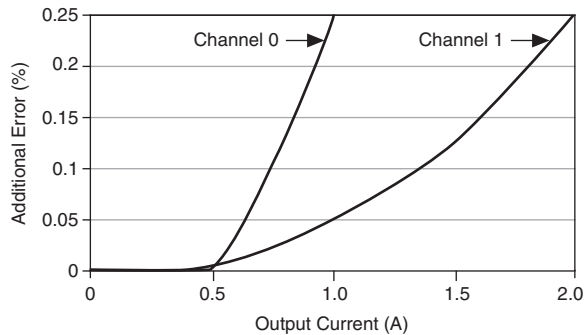
Channel(s)	Current Limit Range	Voltage Level Range (V)	Voltage Level (V)	Iteration	Output	As Found/As Left Limit ± (% of reading + offset)
1	20 mA	20	0	1	5.00 mA	0.03% + 2.0 μA
			20	2	5.00 mA	
				3	10.0 mA	
				4	15.0 mA	
				5	20.0 mA	
			-20	6	5.00 mA	
1	20 mA	20 V	-20	7	10.0 mA	0.03% + 2.0 μA
				8	15.0 mA	
				9	20.0 mA	
	200 mA		0	1	50.0 mA	0.03% + 40 μA
			20	2	50.0 mA	
				3	100 mA	
				4	150 mA	
				5	200 mA	
			-20	6	50.0 mA	
				7	100 mA	
				8	150 mA	
				9	200 mA	

Table 8. NI 4130 Output Parameters and As Found/As Left Limits for Current Measurement Accuracy Verification (Continued)

Channel(s)	Current Limit Range	Voltage Level Range (V)	Voltage Level (V)	Iteration	Output	As Found/As Left Limit ± (% of reading + offset)
1	2 A	20 V	0	1	0.5 A	0.12% + 200 μA ¹
			20	2	0.5 A	
				3	1.0 A	
				4	1.5 A	
				5	2.0 A	
			-20 V	6	0.5 A	
				7	1.0 A	
				8	1.5 A	
				9	2.0 A	

¹ For currents ≥ 500 mA, refer to the additional derating information in Figure 5, *Accuracy Derating versus Load Current*.

Figure 5. Accuracy Derating versus Load Current



Verifying Load Regulation

Complete the load regulation test to verify that the output voltage falls within specified limits when the load current changes, or that the output current falls within specified limits when the load voltage changes. Each test requires an external load to vary the load voltage or current. Load Regulation Verification results are dependent upon voltage and current measurement accuracy. Any failure of the Voltage Measurement Verification or Current Measurement Verification steps may result in a failure of the Load Regulation Verification steps.

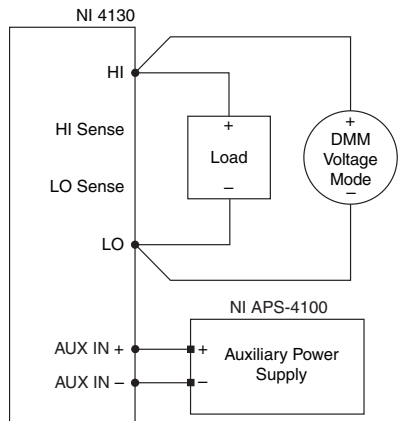
Connect the NI APS-4100 to the Aux Power Input connections for load regulation tests.

Refer to the [Verifying Voltage Measurement Accuracy](#) section and the [Verifying Current Measurement Accuracy](#) section for instructions on running these measurement accuracy tests.

Voltage Load Regulation

To verify voltage load regulation, use the NI 4130 in Constant Voltage mode and confirm that the output voltage change falls within calculated limits while varying the load current using an external load. Table 9 lists the resistance values and measurements needed to complete verification. Refer to Figure 6 for the necessary output connections.

Figure 6. Voltage Load Regulation Verification Connection Diagram



1. For each test, connect the first specified resistance (R_1) in Table 10 to the specified channel of the NI 4130.
2. Wait two seconds for the NI 4130 output to settle.
3. While taking a current measurement with the NI 4130 (I_1), use the DMM to measure the voltage across the output of the NI 4130 (V_1).
4. Change the load from R_1 to R_2 and repeat the previous step.
5. Record the voltage (V_2) and current (I_2) measurements for the new resistance (R_2).
6. Calculate the *Voltage Change Limit* using the formulas in Table 9, where the current is in amps.

Table 9. NI 4130 Voltage Load Regulation Voltage Change Limit Formulas

Channel	Voltage Change Limit
0	$\pm (I_1 - I_2) \times 0.0252$
1	$\pm (I_1 - I_2) \times 0.02$

7. Subtract the two voltage measurements, $V_1 - V_2$ to calculate the *Voltage Change*. The test passes if the *Voltage Change* falls within the calculated *Voltage Change Limit*.
8. Repeat steps 1 through 7 for each channel and current range listed in Table 10.

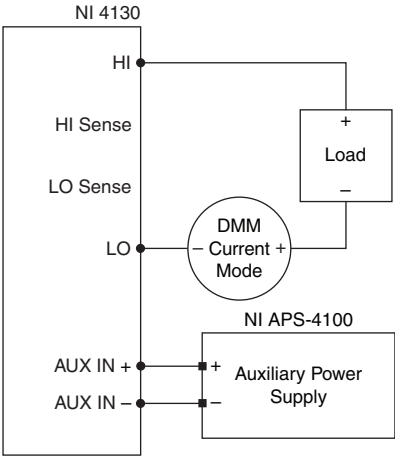
Table 10. NI 4130 Voltage Load Regulation Verification Points

Channel	V Range	V Level	I Range	I Limit	Load R ₁	Load R ₂	Measured				Voltage Change Limit (V)	Voltage Change (V)
							I ₁ (A)	V ₁ (V)	I ₂ (A)	V ₂ (V)		
0	6 V	6 V	1 A	1 A	620 Ω	7 Ω						
1	20 V	10 V	2 A	2 A	1 kΩ	6 Ω						

Current Load Regulation

To verify current load regulation, use the NI 4130 in Constant Current mode and confirm that the output current change falls within calculated limits while varying the load voltage using different resistors. Table 11 lists the resistance values and measurements needed to complete verification. Refer to Figure 7 for the necessary connections.

Figure 7. Current Load Regulation Verification Connection Diagram



Complete the following steps to verify the current load regulation. Note the following terms referenced in the procedure:

- (V_1) = 1st NI 4130 Voltage Measurement
 - (I_1) = 1st DMM Current Measurement
 - (V_2) = 2nd NI 4130 Voltage Measurement
 - (I_2) = 2nd DMM Current Measurement
1. For each test, connect the first specified resistance (R_1) in Table 12 to the specified channel of the NI 4130.
 2. Wait 60 seconds for the NI 4130 output to settle.
 3. While taking a voltage measurement with the NI 4130 (V_1), use the DMM in series to measure the output current (I_1).
 4. Change the load from R_1 to R_2 and repeat the previous step.
For each test, the units for all current measurements and calculations should be the same as the *I Range* unit.
 5. Record the current (I_2) and voltage (V_2) measurements for the new resistance (R_2).

6. Calculate the *Current Change Limit* using the formulas shown in the following table:

Table 11. NI 4130 Current Load Regulation Current Change Limit Formulas

Channel	Current Range	Current Change Limit
0	1 A	$\pm 2.00 \times 10^{-4} \times (V_1 - V_2)$
1	200 μ A	$\pm 2.00 \times 10^{-8} \times (V_1 - V_2)$
	2 mA	$\pm 2.00 \times 10^{-7} \times (V_1 - V_2)$
	20 mA	$\pm 2.00 \times 10^{-6} \times (V_1 - V_2)$
	200 mA	$\pm 2.00 \times 10^{-5} \times (V_1 - V_2)$
	2 A	$\pm 2.00 \times 10^{-4} \times (V_1 - V_2)$

7. Subtract the two current measurements, $I_1 - I_2$ to calculate the *Current Change*. The test passes if the *Current Change* falls within the calculated *Current Change Limit*.
8. Repeat steps 1 through 7 for each channel and current range listed in Table 12.

Table 12. NI 4130 Current Load Regulation Verification Points

Channel	V Range	I Range	V Limit	I Level	Load R ₁	Load R ₂	Measured				Current Change Limit (A)	Current Change (A)
							I ₁ (A)	V ₁ (V)	I ₂ (A)	V ₂ (V)		
0	6 V	1 A	6 V	500 mA	10 Ω	4 Ω						
1	20 V	200 μA	20 V	100 μA	180 kΩ	20 kΩ						
1	20 V	2 mA	20 V	1 mA	18 kΩ	2 kΩ						
1	20 V	20 mA	20 V	10 mA	1.8 kΩ	200 Ω						
1	20 V	200 mA	20 V	100 mA	180 Ω	20 Ω						
1	20 V	2 A	20 V	1 A	18 Ω	2 Ω						

Verifying Line Regulation

Complete the line regulation test to verify that the output voltage falls within specified limits when the line voltage coming from the auxiliary power supply changes or that the output current falls within specified limits when the line voltage changes. Each test requires a variable auxiliary power to vary the line voltage or current. An NI APS-4100 is not sufficient for verifying line regulation because the output voltage is fixed.



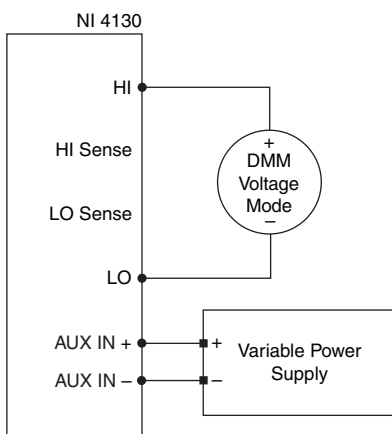
Note Run this test only after the verifying the voltage measurement accuracy and current measurement accuracy tests have passed.

Refer to the [Verifying Voltage Measurement Accuracy](#) section and the [Verifying Current Measurement Accuracy](#) section for instructions about running these measurement accuracy tests.

Voltage Line Regulation

To verify voltage line regulation, use the NI PXI-4130 in constant voltage mode and confirm that the output voltage change falls within calculated limits while varying the line voltage using a variable power supply. Table 14 lists the voltage values and measurements needed to complete verification. Refer to Figure 8 for the necessary connections.

Figure 8. Voltage Line Regulation Verification Connection Diagram



Complete the following steps to verify voltage load regulation:

1. For each test, adjust the external variable power supply to the specified voltage (V_{ext}) listed in Table 14.
2. Set the NI 4130 to output the voltage specified in Table 14.
3. Wait one second for the output to settle.
4. Use the DMM to measure the voltage across the output of the specified channel of the NI 4130 (V_1).

- Change the external variable power supply voltage from V_{ext1} to V_{ext2} , repeat the previous step, and record the voltage of the DMM as V_2 .
- Calculate the *Voltage Change Limit* using the formula in Table 13.

Table 13. NI PXI-4130 Voltage Line Regulation Voltage Change Limit Formulas

Channel	Voltage Change Limit
1	$\pm ((V_1 \times 1.00 \times 10^{-4}) + 1.00 \times 10^{-3}) \times (V_{\text{ext1}} - V_{\text{ext2}})$

- Subtract the two voltage measurements, $V_1 - V_2$ to calculate the *Voltage Change*. The test passes if the *Voltage Change* falls within the calculated *Voltage Change Limit*.
- Repeat steps 1 through 7 for each channel and current range listed in Table 14.

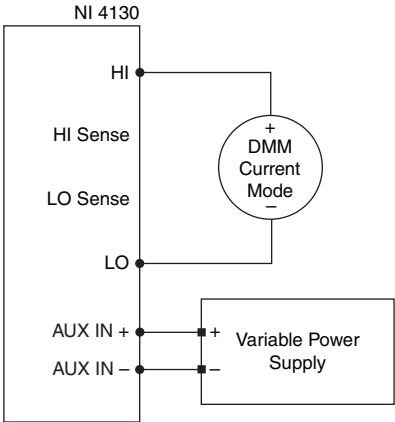
Table 14. NI PXI-4130 Voltage Line Regulation Verification Points

Channel	V Range	V Level	I Range	I Limit	V _{ext1}	V _{ext2}	Measured		Voltage Change Limit (V)	Voltage Change (V)
							V ₁ (V)	V ₂ (V)		
1	20 V	10 V	2 A	100 mA	15.5 V	11 V				

Current Line Regulation

To verify current line regulation, use the NI 4130 in Constant Current mode and confirm the output current change falls within calculated limits while varying the line voltage using a variable power supply. Table 16 lists the voltage values and current measurements needed to complete verification. Refer to Figure 9 for the necessary connections.

Figure 9. Current Line Regulation Verification Connection Diagram



Complete the following steps to verify current load regulation:

1. For each test, adjust the external variable power supply to the specified voltage (V_{ext1}) listed in Table 16.
2. Set the NI 4130 to output the current specified in Table 16.
3. Wait 60 seconds for the output to settle.
4. Use the DMM to measure the current across the output of the specified channel of the NI 4130 (I_1).
5. Change the external variable power supply voltage from V_{ext1} to V_{ext2} , repeat the previous step, and record the current of the DMM as I_2 .
6. Calculate the current change limit using the formulas shown in the following table:

Table 15. NI 4130 Current Line Regulation Current Change Limit Formulas

Channel	Current Range	Current Change Limit
1	200 μ A	$\pm ((I_1 \times 1.00 \times 10^{-4}) + 4.00 \times 10^{-8}) \times (V_{ext1} - V_{ext2})$
1	2 mA	$\pm ((I_1 \times 1.00 \times 10^{-4}) + 4.00 \times 10^{-7}) \times (V_{ext1} - V_{ext2})$
1	20 mA	$\pm ((I_1 \times 1.00 \times 10^{-4}) + 4.00 \times 10^{-6}) \times (V_{ext1} - V_{ext2})$
1	200 mA	$\pm ((I_1 \times 1.00 \times 10^{-4}) + 4.00 \times 10^{-5}) \times (V_{ext1} - V_{ext2})$
1	2 A	$\pm ((I_1 \times 1.00 \times 10^{-4}) + 4.00 \times 10^{-4}) \times (V_{ext1} - V_{ext2})$

7. Subtract the two voltage measurements, $I_1 - I_2$ to calculate the *Current Change*. The test passes if the *Current Change* falls within the calculated *Current Change Limit*.
8. Repeat steps 1 through 7 for each channel and current range listed in Table 16.

Table 16. NI 4130 Current Line Regulation Verification Points

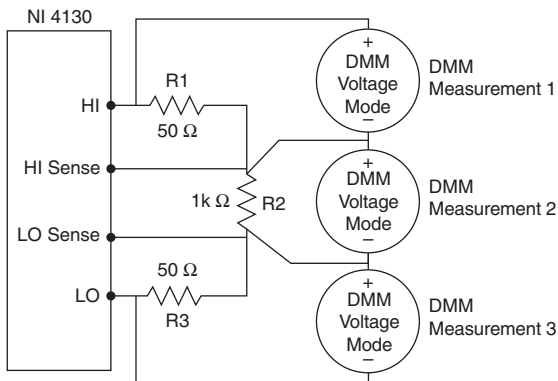
Channel	V Range	I Range	V Limit	I Level	V _{ext1}	V _{ext2}	Measured		Current Change Limit (A)	Current Change (A)
							I ₁ (A)	I ₂ (A)		
1	20 V	200 µA	10 V	200 µA	15.5 V	11 V				
1	20 V	2 mA	10 V	2 mA	15.5 V	11 V				
1	20 V	20 mA	10 V	20 mA	15.5 V	11 V				
1	20 V	200 mA	10 V	200 mA	15.5 V	11 V				
1	20 V	2 A	10 V	2 A	15.5 V	11 V				

Verifying Remote Sense Output

To verify remote sense, complete the following steps using a test circuit of three resistors that simulates the voltage drop between the device and a load.

1. Connect a $50\ \Omega$ (R_1), $1\ \text{k}\Omega$ (R_2), and $50\ \Omega$ (R_3) resistor in series, with the $1\ \text{k}\Omega$ resistor being the center resistor, as shown in Figure 10.

Figure 10. Remote Sense Output Verification Connection Diagram



2. Connect the resistors to the HI and LO terminals on the NI 4130 as shown in Figure 10. Connect the remote sense leads directly across the $1\ \text{k}\Omega$ resistor (R_2).
3. With remote sense on and a current limit of 100 mA, generate 10 V in the 20 V range.
4. Measure the *HI Lead Drop* with the DMM (*DMM Measurement 1*) from the HI terminal of the NI 4130 to the HI side of the $1\ \text{k}\Omega$ resistor.
5. Measure the *LO Lead Drop* with the DMM (*DMM Measurement 3*) from the LO side of the $1\ \text{k}\Omega$ resistor to the LO terminal of the NI 4130.
6. Calculate the accuracy limit for the load voltage using the following equation:

$$\text{Load Voltage Limit} = 10\ \text{V} \pm (.0052\ \text{V} + (0.000120\ \text{V} \times (\text{HI Lead Drop} + \text{LO Lead Drop})))$$
7. Measure the load voltage with the DMM (*DMM Measurement 2*) across the $1\ \text{k}\Omega$ load where the sense leads connect. The test passes if the *Load Voltage* measurement falls within the calculated *Load Voltage Limit*.

Table 17. NI 4130 Remote Sense Output Verification Points

V Range	V Level	I Range	I Limit	Measured Load Voltage (V)	Measured HI Lead Drop (V)	Measured LO Lead Drop	Load Voltage Upper Limit (V)	Load Voltage Lower Limit (V)
20 V	10 V	200 mA	100 mA					

Adjustment

Adjustment improves the accuracy of the NI 4130 and updates the calibration date and temperature in the EEPROM. Perform an adjustment once a year or when the accuracy of NI 4130 is outside the calibration As Found/As Left limits.

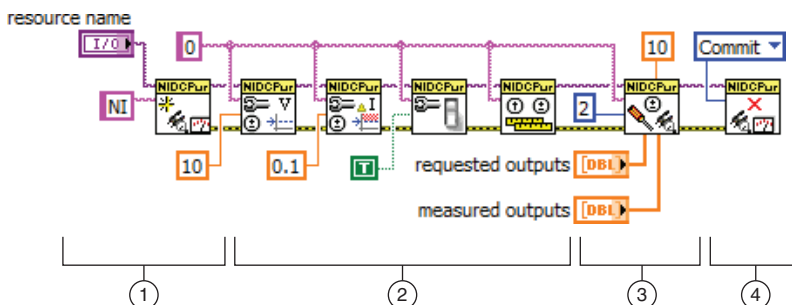
Adjustment corrects the following NI 4130 specifications:

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

Considerations

The figure below represents the general flow of an application used to adjust a range on a single channel of the NI 4130.

Figure 11. LabVIEW Block Diagram Illustrating Adjustment on the NI 4130



1. **Initialize external calibration session:** To adjust the NI 4130, call the niDCPower Initialize External Calibration VI (niDCPower_InitExtCal function) to initiate a special type of NI-DCPower session. The default calibration password is NI.
2. **Configure the instrument:** Call a series of standard NI-DCPower VIs/functions specific to the adjustment of a particular range. These calls vary depending on the requirements of the range being adjusted. Typical operations in this step include configuring ranges, setting output levels, or taking measurements. Measurements made by external equipment required for adjustment also occur during this step. For assistance configuring the NI 4130 to a particular output or measurement mode, refer to the example programs installed with NI-DCPower.
3. **Call niDCPower Cal Adjust function(s):** When the measurements required for adjustment of a range are complete, call one of the niDCPower Cal Adjust VIs or functions to calculate new calibration coefficients and store them in memory on the host. Calling these VIs/functions does not commit the new coefficients to hardware.

4. **Close session and commit new calibration coefficients:** To complete adjustment of the range, call the niDCPower Close External Calibration VI (niDCPower_CloseExtCal function) to close the session. To write new calibration coefficients to the hardware, specify an action of **Commit**. At this time, the calibration date and temperature stored onboard are also updated.



Note You can adjust any voltage or current range individually by opening a calibration session, adjusting, and then closing the session with an action of **Commit**. To adjust all voltage and current ranges simultaneously, open a single calibration session, execute multiple adjustment steps, and then close the session with an action of **Commit** to write coefficients for multiple ranges simultaneously.



Note If the NI 4130 passes initial verification and is within all test limits, NI recommends, but does not require, an adjustment to guarantee the published specifications for the next year. If you choose to skip adjustment, run the niDCPower Initialize External Calibration VI and end with the niDCPower Close External Calibration VI with **action** set to **Commit** to update the calibration date and onboard calibration temperature without making any adjustments to the device.

After adjustment, repeat the *Verification* section to verify that the adjustment was successful.

Adjusting Voltage Programming Accuracy

To adjust voltage programming, compare a set of requested voltage output points to the actual voltage as measured by an external DMM. Configure the voltage level using the *Output* value for the iteration of channel x in Table 18.

To ensure the system has had adequate time to settle, wait one second after requesting a new voltage before taking a measurement with the DMM.

Use the niDCPower Cal Adjust Voltage Level VI (niDCPower_CalAdjustVoltageLevel function) to calculate the new calibration coefficients. Pass the voltage setpoints requested by the NI 4130 to the Requested Outputs input of the VI and the voltage values measured by the DMM to the Measured Outputs input of the VI. Call this VI or function once for the positive setpoints and once for the negative setpoints specified for each range in Table 18.

Figure 12. Voltage Adjustment Connection Diagram

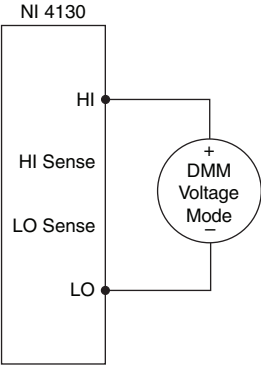


Table 18. NI 4130 Output Parameters for Voltage Programming Accuracy Adjustment

Channel	Iteration	Voltage Level Range (V)	Output	Current Limit (A)
0	1	6	0 V	0.5
	2		3 V	
	3		6 V	
1	1	6	1 mV	
	2		3 V	
	3		6 V	
	4		-0.1 mV	
	5		-3 V	
	6		-6 V	
	1	20	1 mV	
	2		10 V	
	3		20 V	
	4		-1 mV	
	5		-10 V	
	6		-20 V	

Adjusting Voltage Measurement Accuracy

To adjust voltage measurement, compare a set of voltage output points as measured by an external DMM to the measured voltage reported by the NI 4130. Configure the voltage level using the *Output* value for the iteration of channel *x* in Table 19. Refer to the figure below for the necessary connections.

To ensure the system has had adequate time to settle, wait one second after requesting a new voltage before taking a measurement with the DMM. Set the Samples to Average property to 300.

Use the `niDCPower Cal Adjust Voltage Measurement VI` (`niDCPower_CalAdjustVoltageMeasurement` function) to calculate the new calibration coefficients. Pass the voltage values reported by the NI 410 to the Reported Outputs input of the VI, and pass the voltage values measured by the DMM to the Measured Outputs input of the VI. Call this VI or function once per range.

Figure 13. Voltage Adjustment Connection Diagram

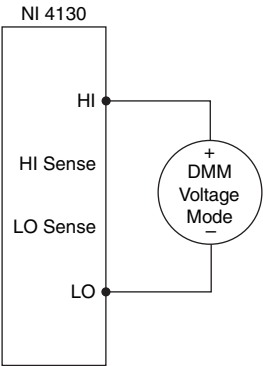


Table 19. NI 4130 Output Parameters for Voltage Measurement Accuracy Adjustment

Channel	Iteration	Voltage Level Range (V)	Output (V)	Current Limit (A)
0	1	6	0	0.5
	2		3	
	3		6	
1	1	20	-20	
	2		0	
	3		20	

Adjusting Current Programming Accuracy

Connect the NI 4130 channel x to the DMM or to the Fluke 5700A/5720A/5730A calibrator, as illustrated in Figure 3 or Figure 4. Configure the DMM to the mode and range listed for the corresponding channel and range in Table 4. When applicable, configure the Fluke 5700A/5720A/5730A calibrator to the *Resistance* value for the corresponding channel and range in Table 4. Enable external sense (4-wire mode) on the calibrator. Record the resistance value displayed by the calibrator.

The setup in Figure 3 is used for the 200 μ A, 2 mA, 20 mA, and 200 mA current ranges of channel 1. The setup in Figure 4 is used for the 1 A current range of channel 0 and the 2 A current range of channel 1.

To ensure the system has had adequate time to settle, wait one second after requesting a new set of parameters before taking a measurement with the DMM. Set the *Overranging Enabled* property of the NI 4130 to *True*.

For the 200 μ A, 2 mA, 20 mA, and 200 mA current ranges of channel 1, divide the voltage measurement you recorded with the DMM by the resistance measurement you recorded from the calibrator to calculate the output current. For the 1 A current range of channel 0 and the 2 A current range of channel 1, the DMM measures the output current directly. Subtract the *Output* value for the iteration of channel x in Table 20 from the output current calculated above to obtain the output error.

Pass the requested current setpoints and measured current values to the *niDCPower Cal Adjust Current Limit VI* (*niDCPower_CalAdjustCurrentLimit* function) to calculate the new calibration coefficient values. Each current limit range requires a unique call to the *niDCPower Cal Adjust Current Level VI*. For channel 1, each current limit range has one set of iterations with a positive voltage level and another set with a negative voltage level. Within the same current limit range, outputs related to the positive voltage level and outputs related to the negative voltage level require unique calls to the *niDCPower Cal Adjust Current Level VI*.

Refer to the *Output* column of Table 20 for the current limit for each iteration.

After applying a new set of configurations to the NI 4130, wait 3 seconds before taking a new measurement with the DMM or the NI 4130.

Table 20. NI 4130 Output Parameters for Current Programming
Accuracy Adjustment

Channel	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output
0	1 A	6 V	6 V	1	20 mA
				2	350 mA
				3	700 mA
1	200 μ A	20 V	20 V	1	2.00 μ A
				2	24.0 μ A
				3	46.0 μ A
				4	68.0 μ A
				5	90.0 μ A
				6	112 μ A
				7	134 μ A
				8	156 μ A
				9	178 μ A
				10	200 μ A
			-20 V	11	2.00 μ A
				12	24.0 μ A
				13	46.0 μ A
				14	68.0 μ A
				15	90.0 μ A
				16	112 μ A
				17	134 μ A
				18	156 μ A
				19	178 μ A
				20	200 μ A

Table 20. NI 4130 Output Parameters for Current Programming
Accuracy Adjustment (Continued)

Channel	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output
1	2 mA	20 V	20 V	1	20.0 μA
				2	0.240 mA
				3	0.460 mA
				4	0.680 mA
				5	0.900 mA
				6	1.12 mA
				7	1.34 mA
				8	1.56 mA
				9	1.78 mA
				10	2.00 mA
			-20 V	11	20.0 μA
				12	0.240 mA
				13	0.460 mA
				14	0.680 mA
				15	0.900 mA
				16	1.12 mA
				17	1.34 mA
				18	1.56 mA
				19	1.78 mA
				20	2.00 mA
	20 mA	20 V	1	0.200 mA	
			2	2.40 mA	
			3	4.60 mA	

Table 20. NI 4130 Output Parameters for Current Programming
Accuracy Adjustment (Continued)

Channel	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output
1	20 mA	20 V	20 V	4	6.80 mA
				5	9.0 mA
				6	11.2 mA
				7	13.4 mA
				8	15.6 mA
				9	17.8 mA
				10	20.0 mA
			-20 V	11	0.200 mA
				12	2.40 mA
				13	4.60 mA
				14	6.80 mA
				15	9.00 mA
				16	11.2 mA
				17	13.4 mA
				18	15.6 mA
				19	17.8 mA
				20	20.0 mA

Table 20. NI 4130 Output Parameters for Current Programming
Accuracy Adjustment (Continued)

Channel	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output
1	200 mA	20 V	20 V	1	2.00 mA
				2	24.0 mA
				3	46.0 mA
				4	68.0 mA
				5	90.0 mA
				6	112 mA
				7	134 mA
				8	156 mA
				9	178 mA
				10	200 mA
			-20 V	11	2.00 mA
				12	24.0 mA
				13	46.0 mA
				14	68.0 mA
				15	90.0 mA
				16	112 mA

Table 20. NI 4130 Output Parameters for Current Programming
Accuracy Adjustment (Continued)

Channel	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output
1	200 mA	20 V	-20 V	17	134 mA
				18	156 mA
				19	178 mA
				20	200 mA
	2 A		20 V	1	20.0 mA
				2	240 mA
				3	460 mA
				4	680 mA
				5	900 mA
				6	1.12 A
				7	1.34 A
				8	1.56 A
				9	1.78 A
				10	2.00 A
			-20 V	11	20.0 mA
				12	240 mA
				13	460 mA
				14	680 mA
				15	900 mA
				16	1.12 A
				17	1.34 A
				18	1.56 A
				19	1.78 A
				20	2.00 A

Adjusting Current Measurement Accuracy

To adjust current measurement, configure the calibrator using the *Calibrator Resistance* value from Table 4, program the NI 4130 according to the values in Table 21, and then compare the current outputs measured by an external DMM to the measured current reported by the NI 4130.

Connect the NI 4130 channel x to the DMM or to the Fluke 5700A/5720A/5730A calibrator, as illustrated in Figure 3 or Figure 4. Configure the DMM to the mode and range listed for the corresponding channel and range in Table 4.

When applicable, configure the Fluke 5700/5720A/5730A calibrator to the *Resistance* value for the corresponding channel and range in Table 4. Enable external sense (4-wire mode) on the calibrator. Record the resistance value displayed by the calibrator.

Set the Samples to Average property of the NI 4130 to 300.



Note When calibrating channel 1, each current limit range requires a unique call to the niDCPower Cal Adjust Current Measurement VI.

Pass the current values reported by the NI 4130 and the current values calculated from the DMM voltage measurements to the niDCPower Cal Adjust Current Measurement VI (niDCPower_CalAdjustCurrentMeasurement function) to calculate the new calibration coefficients. Call this VI or function once per range.

For the 200 μ A, 2 mA, 20 mA, and 200 mA current ranges of channel 1, divide the voltage measurement you recorded with the DMM by the resistance measurement you recorded from the calibrator to calculate the output current. For the 1 A current range of channel 0 and the 2 A current range of channel 1, the DMM measures the output current directly. Subtract the *Output* value for the iteration of channel x in Table 21 from the output current calculated above to obtain the output error.

Refer to the *Output* column of Table 21 for the NI 4130 current limit for each iteration.

After applying a new set of configurations to the NI 4130, wait 3 seconds before taking a measurement with the DMM or the NI 4130.

When you have successfully completed all adjustment tests, close the calibration session with **action** set to **Commit**. Adjustment of the NI 4130 is now complete. Repeat the [Verification](#) section to reverify the performance of the NI 4130 post-adjustment. After reverification, update the verification date and temperature by opening a calibration session, and then close the calibration session with **action** set to **Commit**. If the NI 4130 successfully passes all verification tests, calibration is complete.

If the device has successfully passed all verification tests, the NI 4130 is within the published specifications, and adjustment is optional.

Table 21. NI 4130 Output Parameters for Current Measurement
Accuracy Adjustment

Channel	Current Limit Range	Voltage Level Range	Voltage Level	Iteration	Output
0	1 A	6 V	0 V	1	350 mA
			6 V	2	350 mA
				3	700 mA
1	200 μA	20 V	0 V	1	200 μA
			20 V	2	
			-20 V	3	
	2 mA		0 V	1	2 mA
			20 V	2	
			-20 V	3	
	20 mA		0 V	1	20 mA
			20 V	2	
			-20 V	3	
	200 mA		0 V	1	200 mA
			20 V	2	
			-20 V	3	
	2 A		0 V	1	800 mA
			20 V	2	
			-20 V	3	

Revision History

Part Number	Edition Date	Section	Changes
374753F-01	June 2021	Test Equipment	Added an additional digital multimeter (DMM) and High Power Resistance Decade Box
		Voltage Load Regulation, Current Load Regulation, Voltage Line Regulation, Current Line Regulation	Updated settling times

Worldwide Support and Services

The NI website is your complete resource for technical support. At ni.com/support you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

Visit ni.com/services for information about the services NI offers.

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 North Mopac Expressway, Austin, Texas, 78759-3504, USA. For up-to-date contact information for your location, visit ni.com/contact.

Information is subject to change without notice. Refer to the *NI Trademarks and Logo Guidelines* at ni.com/trademarks for more information on NI trademarks. Other product and company names mentioned herein are trademarks or trade names of their respective companies. For patents covering NI products/technology, refer to the appropriate location: **Help»Patents** in your software, the `patents.txt` file on your media, or the *National Instruments Patents Notice* at ni.com/patents. You can find information about end-user license agreements (EULAs) and third-party legal notices in the readme file for your NI product. Refer to the *Export Compliance Information* at ni.com/legal/export-compliance for the NI global trade compliance policy and how to obtain relevant HTS codes, ECCNs, and other import/export data. NI MAKES NO EXPRESS OR IMPLIED WARRANTIES AS TO THE ACCURACY OF THE INFORMATION CONTAINED HEREIN AND SHALL NOT BE LIABLE FOR ANY ERRORS. U.S. Government Customers: The data contained in this manual was developed at private expense and is subject to the applicable limited rights and restricted data rights as set forth in FAR 52.227-14, DFAR 252.227-7014, and DFAR 252.227-7015.

© 2008–2021 National Instruments Corporation. All rights reserved.