CALIBRATION PROCEDURE

NI PXIe-5451

This document contains information for calibrating the National Instruments PXIe-5451 (NI 5451) arbitrary waveform generator. For more information about calibration, visit `ni.com/calibration`.

Contents

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 should enter from the keyboard, sections of code, programming examples, and syntax examples. This font is also used for the proper names of disk drives, paths, directories, programs, subprograms, subroutines, device names, functions, operations, variables, filenames, and extensions.

Software Requirements

Calibrating the NI 5451 requires installing NI-FGEN version 2.7.3 or later on the calibration system. You can download the NI-FGEN instrument driver from the Drivers and Updates Web site at `ni.com/updates`. NI-FGEN supports programming a self-calibration and an external calibration in the LabVIEW, LabWindows™/CVI™, and C or C++ application development environments (ADEs). When you install NI-FGEN, you only need to install support for the ADE that you intend to use.

LabVIEW support is in the `niFgen.llb` file, and all calibration functions appear in the NI-FGEN Calibration palette. For LabWindows/CVI users, the NI-FGEN function panel (`niFgen.fp`) provides access to the available functions.

For the locations of files you may need to calibrate your device, refer to the *NI-FGEN Instrument Driver Readme*, which is available on the NI-FGEN media.

Note After you install NI-FGEN, you can access the *NI-FGEN Instrument Driver Readme* and other signal generators documentation at **Start»All Programs»National Instruments»NI-FGEN»Documentation**.

Documentation Requirements

The following documents contain information about NI-FGEN and the NI 5451:

- *NI Signal Generators Getting Started Guide*—provides instructions for installing and configuring NI signal generators.
- *NI Signal Generators Help*—includes detailed information about the NI 5451 and the NI-FGEN VIs and functions.

These documents are installed with NI-FGEN. You also can find the latest versions of the documentation at `ni.com/manuals`.

NI recommends referring to the following document online at `ni.com/manuals` to ensure you are using the latest NI 5451 specifications:

- *NI 5451 Specifications*—provides the published specification values for the NI 5451.

Note If you are using NI-FGEN 2.7, the *NI 5451 Specifications* are not installed. You must download the specifications at `ni.com/manuals`.

Password

The default password for password-protected operations is `NI`. This password is required to open an external calibration session.

Calibration Interval

National Instruments recommends a calibration interval of one year for the NI 5451. Adjust the recommended calibration interval based on the measurement accuracy demands of your application.

Test Equipment

Table 1 lists the equipment required to calibrate the NI 5451. If you do not have the recommended equipment, select a substitute calibration standard using the specifications listed in Table 1.

Table 1. Equipment Required for Calibrating the NI 5451

Equipment	Recommended Model	Parameter Measured	Minimum Requirements
Digital multimeter (DMM)	NI PXI-4071	• DC Amplitude/AC Amplitude Channel-to-Channel Relative Accuracy • Differential and Single-Ended Offset • Common Mode Offset • AC Amplitude Accuracy • DC ADC and Reference Adjustment*	DCV accuracy: ≤0.05% DCV input impedance: ≥1 GΩ ACV accuracy: ≤0.13% ACV input impedance: ≥10 MΩ Bandwidth: ≥100 kHz
Digital oscilloscope (DPO)	Tektronix DPO70404	• Channel-to-Channel Timing Alignment Accuracy • Rise/Fall Time† • Aberrations†	Analog bandwidth: ≥4 GHz (–3 dB) Real-time sample rate: 25 GS/s Jitter noise floor: ≤450 fs
Differential probe	Tektronix P7380SMA		Differential rise time: (10% to 90%): ≤55 ps Differential-mode input resistance: 100 Ω Differential bandwidth: ≥4 GHz (–3 dB)

Table 1. Equipment Required for Calibrating the NI 5451 (Continued)

Equipment	Recommended Model	Parameter Measured	Minimum Requirements
Power meter/ sensor (x2)[‡]	Rohde & Schwarz (R&S) NRP-Z91	• Frequency Response (Flatness) Accuracy • Channel-to-Channel Frequency Response (Flatness) Matching Accuracy • Frequency Response (Flatness) Adjustment[*]	VSWR: (50 kHz to 120 MHz) ≤1.11 Relative power accuracy: ≤0.022 dB
Type N(f) to SMA(m) adapter	Maury 8816B		VSWR: (DC to 4 GHz) <1.05
Fixed 7 dB SMA attenuator (x2)	Mini-Circuits VAT-7-1+		VSWR (50 kHz to 120 MHz): 1.02:1 Flatness (50 kHz to 60 MHz): 0.05 dB Flatness (60 MHz to 120 MHz): 0.07 dB
Semi-rigid coaxial cable K(m)-K(f) 5 cm (x2)[‡, **]	Anritsu K120MF-5CM		2 in (m)(f) 50 Ω ±2 Ω Attenuation ≤ 1.6 dB/m at 1 GHz Flatness (50 kHz to 120 MHz): 0.001 dB
50 Ω SMA termination[‡, **]	Anritsu 28K50(m)		50 Ω ±1%

Table 1. Equipment Required for Calibrating the NI 5451 (Continued)

Equipment	Recommended Model	Parameter Measured	Minimum Requirements
Spectrum analyzer	R&S FSU26 or FSUP Required options: • FSU-B23 20 dB preamplifier • FSU-B25 electronic attenuator	• Average Noise Density • Internal Reference Clock Frequency Accuracy • Spurious free dynamic range with harmonics† • Spurious free dynamic range without harmonics† • Total harmonic distortion (THD)† • Intermodulation distortion (IMD_3)†	Frequency accuracy ≤100 Hz Specifications for the following parameters must be better than or equal to the equipment recommended for f ≤200 MHz: • Total level measurement uncertainty • Displayed average noise level SSB phase noise (1 Hz) • Intermodulation Distortion • Total harmonic distortion • Spurious free dynamic range • Reference frequency • RF input VSWR
Phase noise analyzer	R&S FSUP	• Output Phase Noise† • Output Jitter†	SSB phase noise (1 Hz) at the offset frequencies must be at least 3 dB better than the NI 5451 specification.

Table 1. Equipment Required for Calibrating the NI 5451 (Continued)

Equipment	Recommended Model	Parameter Measured	Minimum Requirements
BALUN	Picosecond 5320B	• Average Noise Density • Internal Reference Clock Frequency Accuracy • Spurious free dynamic range with harmonics† • Spurious free dynamic range without harmonics† • Total harmonic distortion (THD)† • Intermodulation distortion (IMD_3)† • Output Phase Noise† • Output Jitter†	BW ≥500 MHz Impedance: 50 Ω (100 Ω differential) Differential balance ≤0.2 dB Return loss >20 dB Rise time <500 ps
SMA torque wrench	—	—	Coupling torque: 56 N–cm (5 lb · in.)
SMA 50 Ω high quality cables (x4)	—	—	1 foot maximum length Matching length ≤±1 ps at 200 MHz

* Adjustment Test

† Optional Test

‡ The procedure can be performed using a single power meter.

** If you are using a single power meter, load the unused terminal with the 7 dB attenuator and the 50 Ω termination to balance the output that does not have a power meter attached. If you are using two power meters throughout the procedure, the 50 Ω SMA termination is not required.

Test Conditions

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

- Keep connections to the NI 5451 short. Long cables and wires act as antennae, picking up noise that can affect measurements.
- Keep the NI 5451 outputs balanced at all times during measurements.
- Keep relative humidity between 10% and 90% noncondensing.
- Maintain a temperature between 18 °C and 28 °C.
- Allow a warm-up time of at least 30 minutes after powering on all hardware, loading the operating system, and, if necessary, enabling the device. Unless manually disabled, the NI-FGEN driver automatically loads with the operating system and enables the device. The warm-up time brings the measurement circuitry of the NI 5451 to a stable operating temperature.
- Perform self-calibration on the device. Do not perform self-calibration until the device has completed the 30-minute warm up.

- Ensure that the PXI Express chassis fan speed is set to HI, that the fan filters, if included, are clean, and that the empty slots contain filler panels.
- Plug the PXI Express chassis and the calibrator into the same power strip to avoid ground loops.

Calibration Procedures

The calibration process includes the following steps:

1. *Initial Setup*—Install the device and configure it in Measurement & Automation Explorer (MAX).
2. *Self-Calibration*—Adjust the self-calibration constants of the device.
3. *Verification*—Verify the existing operation of the device. This step confirms whether the device is operating within its specified range prior to adjustment.
4. *Adjustment*—Perform an external adjustment of the device that adjusts the calibration constants of the device. The adjustment procedure automatically stores the calibration date on the EEPROM to allow traceability.
5. *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.

Initial Setup

The *NI Signal Generators Getting Started Guide* contains information about how to install the software and hardware and how to configure the device in MAX.

Self-Calibration

The NI 5451 is capable of performing self-calibration, which adjusts the gain of the Direct path, gain and offset of the Main path, and channel-to-channel timing alignment. An onboard, 24-bit ADC and precision voltage reference are used to calibrate the DC gain and offset. Onboard channel alignment circuitry is used to calibrate the skew between channels. Appropriate constants are stored in nonvolatile memory, along with the self-calibration date, time, and on-board temperature.

Note For the Direct path only, common mode offset is minimized through active circuitry and is not adjusted in self-calibration. Direct path differential offset is not adjusted during self-calibration.

Self-calibration can be initiated from MAX, the FGEN Soft Front Panel, or programmatically using NI-FGEN.

External Calibration

External calibration involves both verification and adjustment. Verification is the process of testing the device to ensure that the output accuracy is within certain specifications. You can use verification to ensure that the adjustment process was successful.

Adjustment is the process of measuring and compensating for device performance to improve the output accuracy. Performing an adjustment updates the calibration date, resetting the calibration interval. The device is warranted to meet or exceed its published specifications for the duration of the calibration interval.

This document provides two sets of test limits for adjustable specifications, the *As Found Test Limit* and the *After Adjustment Test Limit*. If all of the output errors determined during verification fall within the After Adjustment test limits, the device is warranted to meet or exceed its published specifications for a full calibration interval (one year). For this reason, you must verify against the After Adjustment test limits when performing verification after adjustment. Use the *As Found Test Limit* during initial verification.

Measurement Uncertainty

Measurement uncertainty was calculated in accordance with the method described in ISO GUM (Guide to the Expression of Uncertainty in Measurement), for a confidence level of 95%.

The expressed uncertainty is based on the recommended measurement methodology, standards, metrology best practices and environmental conditions of the National Instruments laboratory. It should be considered as a guideline for the level of measurement uncertainty that can be achieved using the recommended method. It is not a replacement for the user uncertainty analysis that takes into consideration the conditions and practices of the individual user.

Verification

This section provides instructions for verifying the NI 5451 specifications. Refer to Table 1 for recommendations about choosing an instrument for each test.

Required verification tests the following NI 5451 specifications:

- DC voltage amplitude absolute accuracy
- DC voltage differentials offset accuracy
- DC voltage common mode offset accuracy
- DC voltage channel-to-channel relative accuracy
- AC voltage amplitude absolute accuracy
- AC voltage amplitude channel-to-channel relative accuracy
- Channel-to-channel timing alignment accuracy
- Frequency response (flatness) accuracy
- Average noise density
- Internal reference clock frequency accuracy

Optional verification tests the following NI 5451 specifications:

- Channel-to-channel frequency response (flatness) matching accuracy
- Analog bandwidth
- Spurious free dynamic range (SFDR) with and without harmonics
- Total harmonic distortion (THD)
- Intermodulation distortion (IMD_3)
- Rise and fall time
- Aberrations
- Phase noise density and jitter

Verification of the NI 5451 is complete only after you have successfully completed all required tests in this section.

Refer to Figure 1 for the names and locations of the NI PXIe-5451 front panel connectors. You can find information about the functions of these connectors in the *NI Signal Generators Getting Started Guide*.

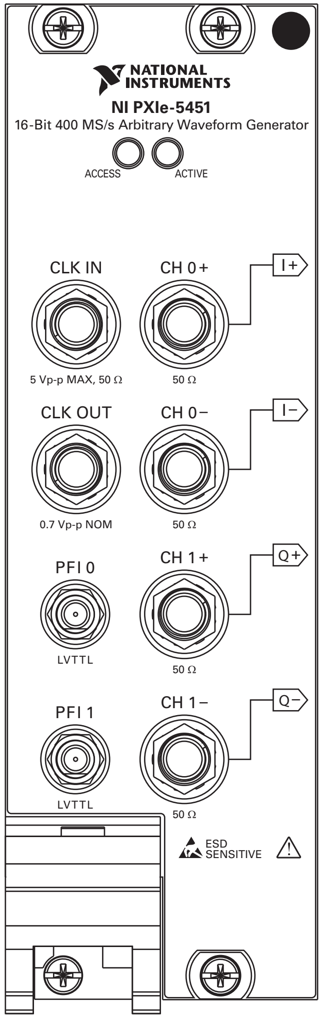


Figure 1. NI PXIe-5451 Front Panel

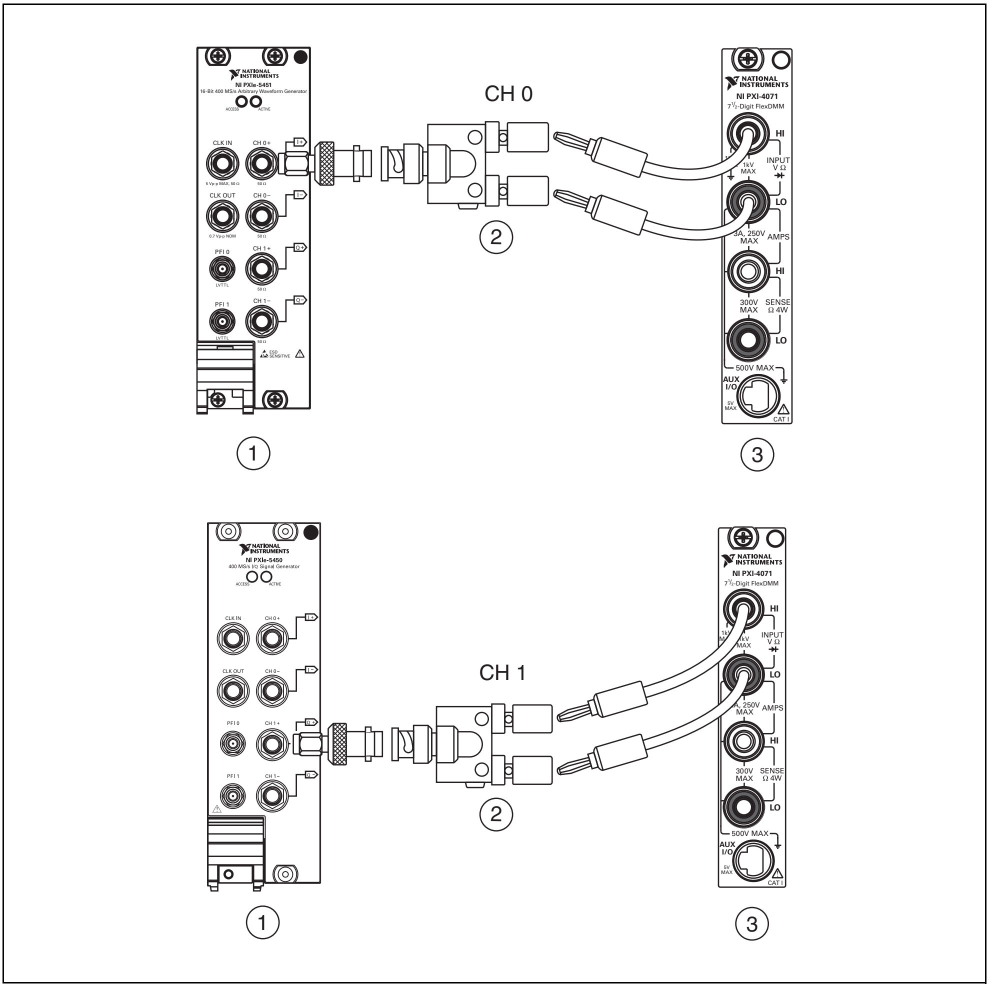
Note The NI 5451 supports both Main path and Direct path operation. Use the Analog Path property or attribute to configure the NI 5451 to generate a waveform via a Main path or a Direct path. Use the Terminal Configuration property or attribute to configure that path as differential or single-ended (Main path only).

Verifying DC Voltage Amplitude Absolute Accuracy

Complete the following steps to verify the DC voltage amplitude absolute accuracy of an NI 5451 module using a digital multimeter (DMM).

Single-Ended Main Path

1. Connect the DMM to the output terminals as shown in Figure 2 for CH 0 to measure the positive channel output with respect to ground.



1 NI 5451	2 Dual banana plug	3 NI PXI-4071

Figure 2. Single-Ended Main Path DC Voltage Amplitude Absolute Accuracy Verification Connections

2. Configure the DMM according to Table 2 and the following characteristics:
   - Function: DC voltage
   - Input impedance: 10 GΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 2, and generate a waveform with the following characteristics:
   - Waveform data amplitude: +1
   - Load impedance: 10 GΩ
   - Flatness correction: Disabled
   - Terminal configuration: Single ended
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage with the DMM.
6. Record the measurement and calculate the output error using the equation in Table 2.
7. Compare the output error to the test limit for the appropriate configuration in Table 2.
8. Repeat steps 2 through 7 for the –1 waveform data amplitude.
9. Repeat steps 2 through 8 for each configuration in Table 2 for CH 0.
10. Set the output voltage level to 0.
11. Connect the DMM to the NI 5451 as shown in Figure 2 for CH 1 to measure the positive channel output with respect to ground.
12. Repeat steps 2 through 10 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 2.

Table 2. Single-Ended Main Path DC Amplitude Absolute Accuracy Verification

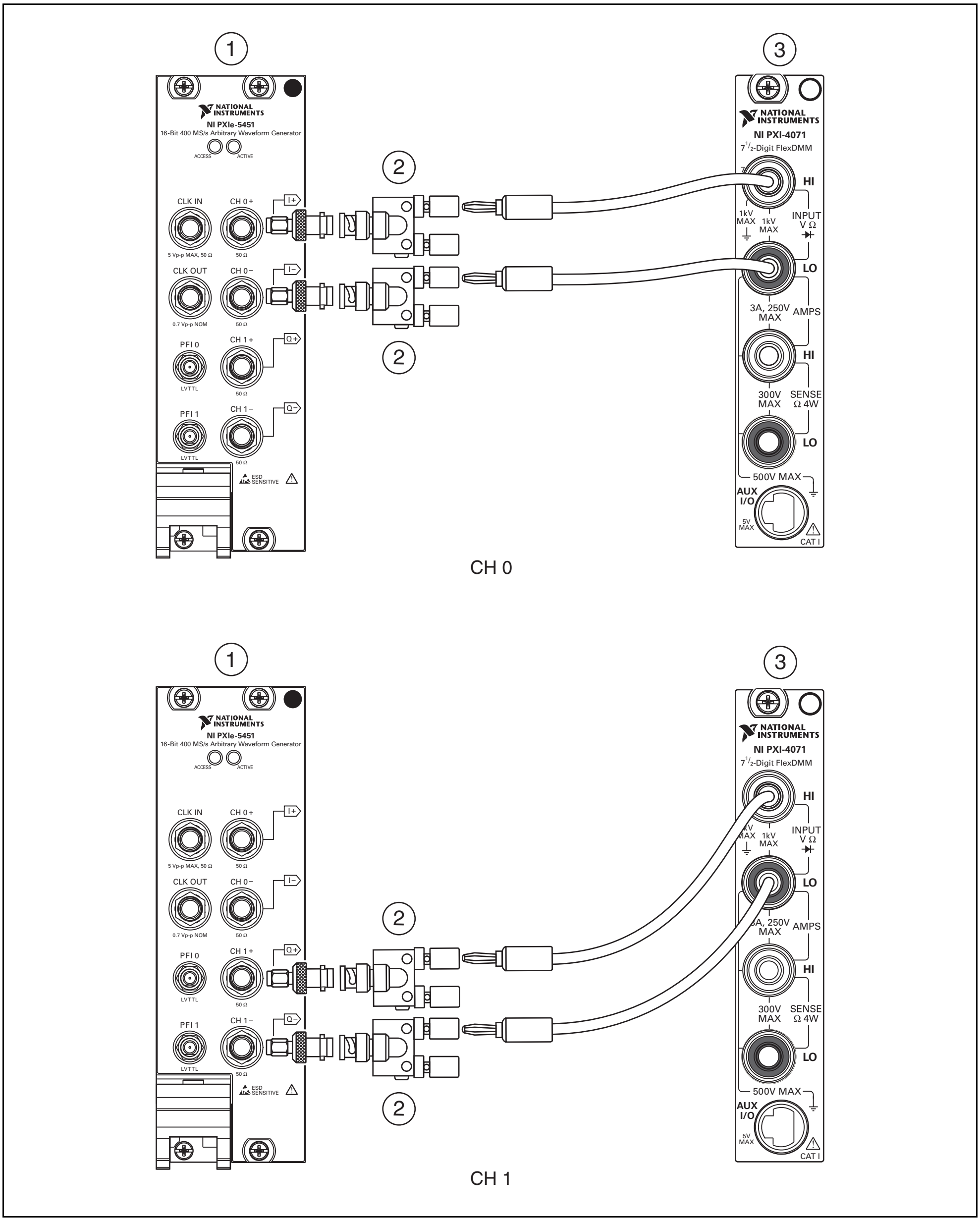
Config.	CH	Gain	Single-Ended Output Range ($V_{pk\text{-}pk}$)	DMM Range (V)	Error*	As Found Test Limit (V)	After Adjustment Test Limit (V)	Measurement Uncertainty (µV)
1	0, 1	2.5	5	10	$\varepsilon = V_{DMM} - V_{Expected}$	±0.020500	±0.011300	±41
2		1.769	3.538	10		±0.014652	±0.008084	±31
3		1.252	2.504	10		±0.010516	±0.005809	±24
4		0.887	1.774	1		±0.007596	±0.004203	±17
5		0.627	1.254	1		±0.005516	±0.003059	±12
6		0.444	0.888	1		±0.004052	±0.002254	±9
7		0.314	0.628	1		±0.003012	±0.001682	±6
8		0.222	0.444	1		±0.002276	±0.001277	±4
9		0.157	0.314	1		±0.001756	±0.000991	±3
10		0.111	0.222	1		±0.001388	±0.000788	±3
11		0.079	0.158	0.1		±0.001132	±0.000648	±3
12		0.055	0.110	0.1		±0.000940	±0.000542	±2
13		0.039	0.078	0.1		±0.000812	±0.000472	±2
14		0.028	0.056	0.1		±0.000724	±0.000423	±1
15		0.019	0.038	0.1		±0.000652	±0.000384	±1
16		0.014	0.028	0.1		±0.000612	±0.000362	±1
17		0.009	0.018	0.1		±0.000572	±0.000340	±1
18		0.007	0.014	0.1		±0.000556	±0.000331	±1
19		0.004	0.008	0.1		±0.000532	±0.000318	±1
20		0.003	0.006	0.1		±0.000524	±0.000313	±1
21		0.002	0.004	0.1		±0.000516	±0.000309	±1
22		0.0018	0.0036	0.1		±0.000514	±0.000308	±1

* $V_{Expected}$ is equal to the waveform data amplitude (+1, –1) multiplied by gain.

Differential Main Path

1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3.

Note The channel signal is connected differentially to the DMM. Signal grounds can be connected together if necessary but should remain floating.



1	NI 5451	2	Dual banana plug	3	NI PXI-4071

Figure 3. Differential DC Voltage Amplitude Absolute Accuracy Verification Connections for the NI 5451

2. Configure the DMM according to Table 3 and the following characteristics:
   - Function: DC voltage
   - Input impedance: 10 GΩ
   - Average reading: 4
3. Configure the NI 5451 according to Table 3, and generate a waveform with the following characteristics:
   - Waveform data amplitude: +1
   - Load impedance: 10 GΩ
   - Flatness correction: Disabled
   - Terminal configuration: Differential
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage with the DMM.
6. Record the measurement and calculate the output error using the equation in Table 3.
7. Compare the output error to the test limit for the appropriate configuration in Table 3.
8. Repeat steps 2 through 7 for the –1 waveform data amplitude.
9. Repeat steps 2 through 8 for each configuration in Table 3 for CH 0.
10. Set the output voltage level to 0.
11. Connect the differential CH 1 on the NI 5451 to the DMM, as shown in Figure 3.
12. Repeat steps 2 through 10 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 3.

Table 3. Differential Main Path DC Voltage Amplitude Absolute Accuracy Verification

Config.	CH	Gain	Differential Output Range (V_{pk-pk})	DMM Range (V)	Error*	As Found Test Limit (V)	After Adjustment Test Limit (V)	Measurement Uncertainty (µV)
1	0, 1	5	10	10	$\varepsilon = V_{DMM} - V_{Expected}$	±0.061000	±0.044800	±126
2		3.539	7.078	10		±0.043468	±0.031943	±90
3		2.505	5.010	10		±0.031060	±0.022844	±65
4		1.774	3.548	10		±0.022288	±0.016411	±49
5		1.255	2.510	10		±0.016060	±0.011844	±34
6		0.889	1.778	1		±0.011668	±0.008623	±25
7		0.629	1.258	1		±0.008548	±0.006335	±18
8		0.445	0.890	1		±0.006340	±0.004716	±13
9		0.315	0.630	1		±0.004780	±0.003572	±9
10		0.223	0.446	1		±0.003676	±0.002762	±7
11		0.158	0.316	1		±0.002896	±0.002190	±7
12		0.111	0.222	1		±0.002332	±0.001777	±5
13		0.079	0.158	0.1		±0.001948	±0.001495	±4
14		0.056	0.112	0.1		±0.001672	±0.001293	±3
15		0.039	0.078	0.1		±0.001468	±0.001143	±2
16		0.028	0.056	0.1		±0.001336	±0.001046	±2
17		0.019	0.038	0.1		±0.001228	±0.000967	±1
18		0.014	0.028	0.1		±0.001168	±0.000923	±1
19		0.009	0.018	0.1		±0.001108	±0.000879	±1
20		0.007	0.014	0.1		±0.001084	±0.000862	±1
21		0.005	0.010	0.1		±0.001060	±0.000844	±1
22		0.0036	0.0072	0.1		±0.001043	±0.000832	±1

* $V_{Expected}$ is equal to the waveform data amplitude (+1, −1) multiplied by gain.

Differential Direct Path

1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3.
2. Configure the DMM according to Table 4 and the following characteristics:
   - Function: DC voltage
   - Input impedance: 10 GΩ
   - Average reading: 4
3. Configure the NI 5451 according to Table 4, and generate a waveform with the following characteristics:
   - Gain: 1
   - Load impedance: 10 GΩ
   - Flatness correction: Disabled
   - Terminal configuration: Differential
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage with the DMM.
6. Record the measurement and calculate the output error using the equation in Table 4.
7. Compare the output error to the test limit for the appropriate configuration in Table 4.
8. Repeat steps 2 through 7 for each configuration in Table 4 for CH 0.
9. Set the output voltage level to 0.
10. Connect the differential CH 1 on the NI 5451 to the DMM, as shown in Figure 3.
11. Repeat steps 2 through 10 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 4.

Table 4. Differential Direct Path DC Voltage Amplitude Absolute Accuracy Verification

Config.	CH	Waveform Data Amplitude (V)	Differential Output Range ($V_{pk\text{-}pk}$)	Load Impedance (GΩ)	DMM Range (V)	Error[*]	As Found Test Limit (V)	After Adjustment Test Limit (V)	Measurement Uncertainty (µV)
1	0, 1	+0.1	2	10	0.1	$\varepsilon = V_{DMM} - V_{Expected}$	±0.004	±0.0018	±4
2		+0.5		10	1		±0.004	±0.0018	±15
3		+1.0		10	1		±0.004	±0.0018	±40
4		–0.1		10	0.1		±0.004	±0.0018	±4
5		–0.5		10	1		±0.004	±0.0018	±15
6		–1.0		10	1		±0.004	±0.0018	±40

[*] $V_{Expected}$ is equal to the waveform data amplitude multiplied by gain.

Verifying DC Voltage Offset Accuracy

Complete the following steps to verify the DC voltage offset accuracy of an NI 5451 module using a digital multimeter (DMM).

Single-Ended Main Path

1. Connect the DMM to the output terminals of the NI 5451 as shown in Figure 2 for CH 0 to measure the positive channel output with respect to ground.
2. Configure the DMM according to Table 5 and the following characteristics:
    - Function: DC voltage
    - Input impedance: 10 GΩ
    - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 5, and generate a waveform with the following characteristics:
    - Gain: 2.5
    - Load impedance: 10 GΩ
    - Flatness correction: Disabled
    - Terminal configuration: Single ended
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage using the DMM.
6. Record the measurement and compare it to the test limit in Table 5.
7. Repeat steps 2 through 6 for each configuration in Table 5.
8. Set the output voltage level to 0.
9. Connect the DMM to the output terminals of the NI 5451 as shown in Figure 2 for CH 1 to measure the positive channel output with respect to ground.
10. Repeat steps 2 through 8 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 5.

Table 5. Single-Ended Main Path DC Voltage Offset Accuracy Verification

Config.	CH	Waveform Data Amplitude (V)	Single-Ended Output Range (V_{pk-pk})	Offset	DMM Range	Error* (V)	As Found Test Limit (V)	After Adjustment Test Limit (V)	Measurement Uncertainty (µV)
1	0, 1	0	5	0	0.1	$\varepsilon = V_{Measured} - V_{Expected}$	±0.00325	±0.00275	±3
2				+1	10		±0.00475	±0.00375	±15
3				+2	10		±0.00625	±0.00475	±27
4				–1	10		±0.00475	±0.00375	±15
5				–2	10		±0.00625	±0.00475	±27

* $V_{Expected}$ is equal to (gain * waveform data amplitude) + offset.

Differential Main Path

1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3.
2. Configure the DMM according to Table 6 and the following characteristics:
   - Function: DC voltage
   - Input impedance: 10 GΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 6, and generate a waveform with the following characteristics:
   - Waveform data amplitude: 0 V
   - Gain: 5
   - Load impedance: 10 GΩ
   - Flatness correction: Disabled
   - Terminal configuration: Differential
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage using the DMM.
6. Record the measurement and compare it to the test limit in Table 6.
7. Repeat steps 2 through 6 for each configuration in Table 6.
8. Set the output voltage level to 0.
9. Connect the differential CH 1 on the NI 5451 to the DMM, as shown in Figure 3.
10. Repeat steps 2 through 8 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 6.

Table 6. Differential Main Path DC Voltage Differential Offset Accuracy Verification

Config.	CH	Waveform Data Amplitude (V)	Differential Output Range (V_{pk-pk})	Offset	DMM Range	Error* (V)	As Found Test Limit (V)	After Adjustment Test Limit (V)	Measurement Uncertainty (μV)
1	0, 1	0	10	0	0.1	$\varepsilon = V_{Measured} - V_{Expected}$	±0.003	±0.0025	±3
2			10	+2	10		±0.009	±0.0045	±27
3			10	+4	10		±0.015	±0.0065	±55
4			10	–2	10		±0.009	±0.0045	±27
5			10	–4	10		±0.015	±0.0065	±55

* $V_{Expected}$ is equal to (gain * waveform data amplitude) + offset.

Differential Direct Path

1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3.
2. Configure the DMM with the following characteristics:
   - Function: DC voltage
   - Range: 0.1 V
   - Input impedance: 10 GΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 7, and generate a waveform with the following characteristics:
   - Waveform data amplitude: 0 V
   - Gain: 1
   - Load impedance: 10 GΩ
   - Flatness correction: Disabled
   - Terminal configuration: Differential
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage using the DMM.
6. Record the measurement and compare it to the test limit in Table 7.
7. Set the output voltage level to 0.
8. Connect the differential CH 1 on the NI 5451 to the DMM, as shown in Figure 3.
9. Repeat steps 3 through 7 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 7.

Table 7. Differential Direct Path DC Voltage Differential Offset Accuracy Verification

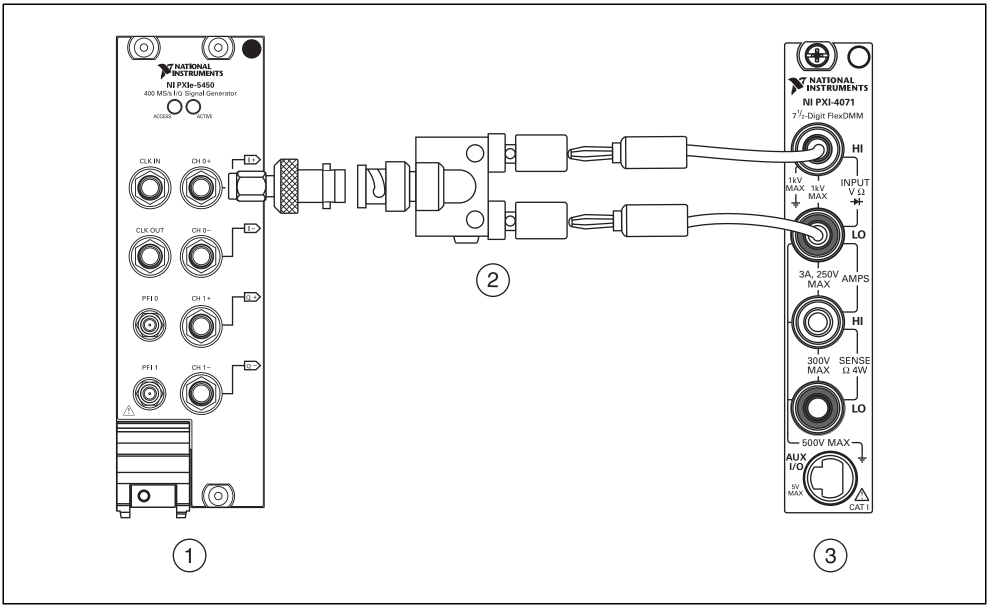
CH	Differential Output Range (V_{pk-pk})	Gain	Load Impedance (GΩ)	Waveform Data Amplitude (V)	As Found Test Limit (mV)	After Adjustment Test Limit (mV)	Measurement Uncertainty (µV)
0, 1	2	1	10	0	±1.0	±0.75	±3.0

Verifying DC Voltage Common Mode Offset Accuracy

Complete the following steps to verify the DC voltage common mode offset accuracy of an NI 5451 module using a digital multimeter.

Differential Main Path

1. Connect the NI 5451 CH 0+ output to the positive input of the DMM and the cable shield ground of the NI 5451 CH 0+ output to the negative input of the DMM, as shown in Figure 4.



1	NI 5451	2	Dual banana plug	3	NI PXI-4071

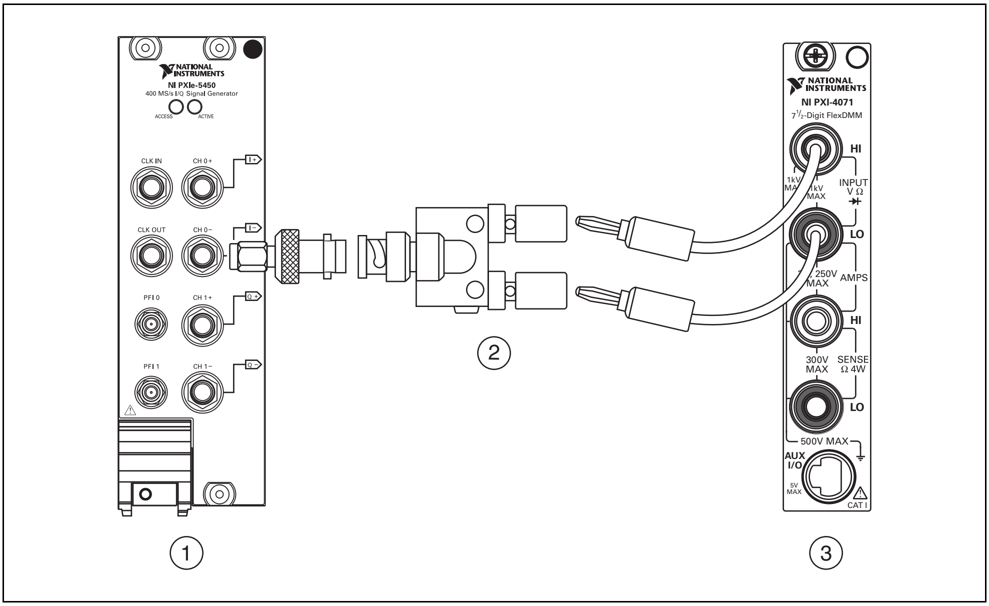
Figure 4. DC Voltage Common Mode Offset Accuracy Verification Connection (CH 0)

2. Configure the DMM according to Table 8 with the following characteristics:
   - Function: DC voltage
   - Range: 0.1 V
   - Input impedance: 10 GΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 8, and generate a waveform with the following characteristics:
   - Waveform data amplitude: 0 V
   - Gain: 5
   - Load impedance: 10 GΩ
   - Flatness correction: Disabled
   - Terminal configuration: Differential
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage using the DMM and record the measurement as $V_{CMO(+)}$.

6. Connect the NI 5451 CH 0– output to the positive input of the DMM and the cable shield ground of the NI 5451 CH 0– output to the negative input of the DMM, as shown in Figure 5.

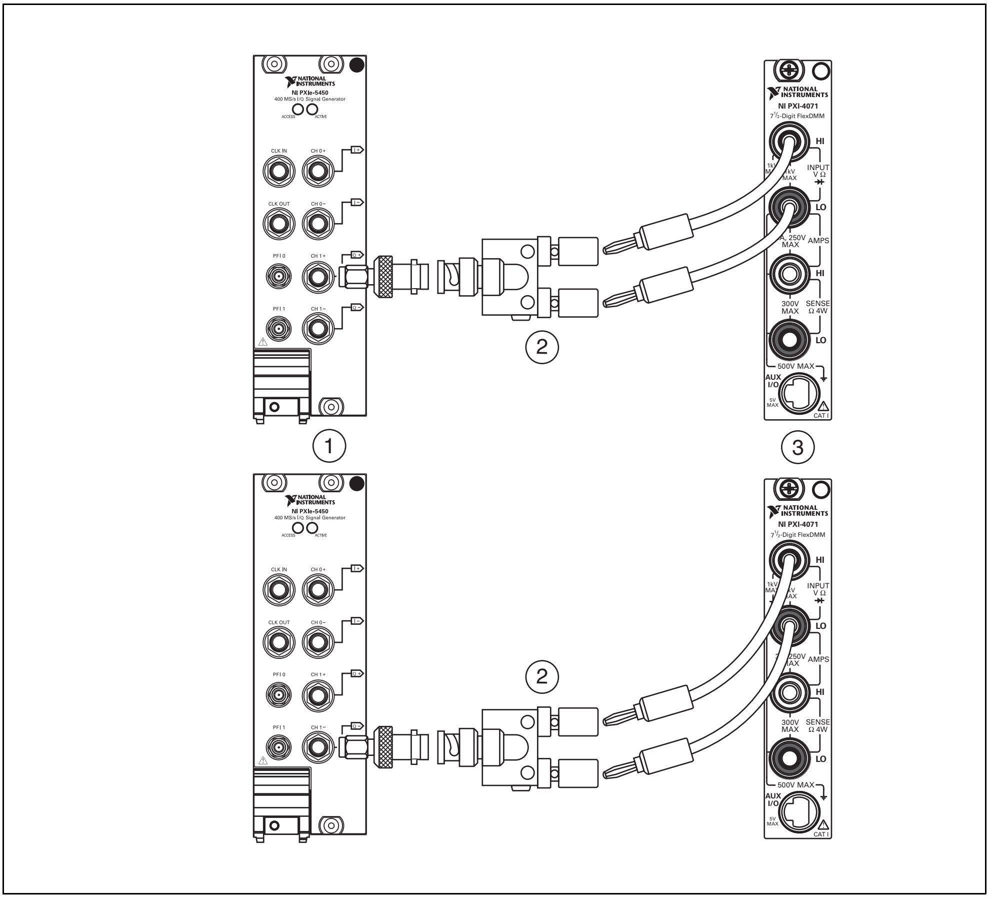


1	NI 5451	2	Dual banana plug	3	NI PXI-4071

Figure 5. DC Voltage Common Mode Offset Accuracy Verification Connection (CH 0)

7. Wait 5 seconds for the equipment to settle.
8. Measure the output voltage using the DMM and record the measurement as $V_{CMO(-)}$.
9. Calculate the error using the equation in Table 8 and compare it to the test limit.
10. Repeat steps 1 through 9 for each configuration in Table 8.

11. Repeat steps 1 through 10 for CH 1. The connections are shown in Figure 6.



1	NI 5451	2	Dual banana plug	3	NI PXI-4071

Figure 6. DC Voltage Common Mode Offset Accuracy Verification Connections (CH 1)

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculation in Table 8.

Table 8. Differential Main Path DC Voltage Common Mode Offset Accuracy Verification

Config.	CH	Waveform Data Amplitude (V)	Common-Mode Offset (V)	DMM Range	Error * (V)	As Found Test Limit (V)	After Adjustment Test Limit (V)	Measurement Uncertainty (µV)
1	0, 1	0	0	0.1	$\varepsilon_{V_{CMO}} = \frac{(V_{CMO(+)} + V_{CMO(-)})}{2} - V_{Expected}$	±0.002	±0.0009	±1.3
2			+1	10		±0.005	±0.0029	±23
3			+2	10		±0.008	±0.0049	±42
4			–1	10		±0.005	±0.0029	±23
5			–2	10		±0.008	±0.0049	±42

* $V_{Expected}$ is equal to common mode offset (V).

Differential Direct Path

1. Connect the NI 5451 CH 0+ output to the positive input of the DMM and the cable shield ground of the NI 5451 CH 0+ output to the negative input of the DMM, as shown in Figure 4.
2. Configure the DMM with the following characteristics:
   - Function: DC voltage
   - Range: 0.1 V
   - Input impedance: 10 GΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 9, and generate a waveform with the following characteristics:
   - Waveform data amplitude: 0 V
   - Gain: 1
   - Load impedance: 10 GΩ
   - Flatness correction: Disabled
   - Terminal configuration: Differential
4. Wait 5 seconds for the equipment to settle.
5. Measure the output voltage using the DMM and record the measurement as $V_{CMO(+)}$.
6. Connect the NI 5451 CH 0– output to the positive input of the DMM and the cable shield ground of the NI 5451 CH 0– output to the negative input of the DMM, as shown in Figure 5.
7. Wait 5 seconds for the equipment to settle.
8. Measure the output voltage using the DMM and record the measurement as $V_{CMO(-)}$.
9. Calculate the error using the equation in Table 9 and compare it to the test limit.
10. Repeat steps 1 through 9 for CH 1. The connections are shown in Figure 6.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculation in Table 9.

Table 9. Differential Direct Path DC Voltage Common Mode Offset Accuracy Verification

CH	Waveform Data Amplitude (V)	Gain	Load Impedance (GΩ)	Error (V)	As Found Test Limit (μV)	After Adjustment Test Limit (μV)	Measurement Uncertainty (μV)
0, 1	0	1	10	$\varepsilon_{V_{CMO}} = \frac{(V_{CMO(+)} + V_{CMO(-)})}{2}$	±350	±250	±1.3

Verifying DC Voltage Channel-to-Channel Relative Accuracy

Complete the following steps to verify the DC voltage channel-to-channel relative accuracy of an NI 5451 module.

Differential Main Path

1. Calculate the DC voltage channel-to-channel relative accuracy for each configuration in Table 10 using the values recorded in step 6 of the *Verifying DC Voltage Amplitude Absolute Accuracy Differential Main Path* section.
2. Compare the errors to the test limits in Table 10.
3. Repeat steps 1 and 2 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 10.

Table 10. Differential Main Path DC Voltage Channel-to-Channel Relative Accuracy Verification

Config.	CH	Gain	Error (V)	Test Limit (V)	Measurement Uncertainty (µV)
1	0, 1	5	$\varepsilon_{0,1} = V_{CH0} - V_{CH1}$	±0.067750	±20
2		3.539		±0.048465	±20
3		2.505		±0.034816	±20
4		1.774		±0.025167	±20
5		1.255		±0.018316	±20
6		0.889		±0.013485	±20
7		0.629		±0.010053	±20
8		0.445		±0.007624	±20
9		0.315		±0.005908	±20
10		0.223		±0.004694	±20
11		0.158		±0.003836	±20
12		0.111		±0.003215	±20
13		0.079		±0.002793	±20
14		0.056		±0.002489	±20
15		0.039		±0.002265	±20
16		0.028		±0.002120	±20
17		0.019		±0.002001	±20
18		0.014		±0.001935	±20
19		0.009		±0.001869	±20
20		0.007		±0.001842	±20
21		0.005		±0.001816	±20
22		0.0036		±0.001798	±20

Differential Direct Path

1. Calculate the DC voltage channel-to-channel relative accuracy for each configuration in Table 11 using the values recorded in step 6 of the *Verifying DC Voltage Amplitude Absolute Accuracy Differential Direct Path* section.
2. Compare the errors to the test limits in Table 11.
3. Repeat steps 1 and 2 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 11.

Table 11. Differential Direct Path DC Voltage Channel-to-Channel Relative Accuracy Verification

Config.	CH	Waveform Data Amplitude	Error (V)	Test Limit (μV)	Measurement Uncertainty (μV)
1	0, 1	+0.1	$\varepsilon_{0,1} = V_{CH0} - V_{CH1}$	±1600	±20
2		+0.5		±1600	±20
3		+1.0		±1600	±20
4		–0.1		±1600	±20
5		–0.5		±1600	±20
6		–1.0		±1600	±20

Verifying AC Voltage Amplitude Absolute Accuracy

Complete the following steps to verify the AC voltage amplitude absolute accuracy of an NI 5451 module using a digital multimeter (DMM).

Single-Ended Main Path

1. Connect the DMM to the NI 5451 as shown in Figure 2 for CH 0 to measure the positive channel output with respect to ground.
2. Configure the DMM according to Table 12 and the following characteristics:
   - Function: AC voltage
   - Input impedance: 10 MΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 12, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Frequency: 50 kHz
   - Sample rate: 400 MS/s
   - Load impedance: 10 MΩ
   - Terminal configuration: Single ended

4. Wait 15 seconds for the output of the NI 5451 to settle.
5. Measure the output voltage amplitude with the DMM.
6. Record the V_{RMS} measurement.
7. Calculate the peak-to-peak amplitude error using the equation in Table 12.
8. Compare the output error to the test limit for the appropriate configuration in Table 12.
9. Repeat steps 2 through 8 for each configuration in Table 12
10. Set the output voltage level to 0.
11. Connect the DMM to the NI 5451 as shown in Figure 2 for CH 1 to measure the positive channel output with respect to ground.
12. Repeat steps 2 through 10 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 12.

Table 12. Single-Ended Main Path AC Voltage Amplitude Absolute Accuracy Verification

Config.	CH	Waveform Data Amplitude	Gain	Single-Ended Output Range ($V_{pk\text{-}pk}$)	Expected (V_{RMS})	DMM Range	Error (V)	As Found Test Limit (V_{RMS})	After Adjustment Test Limit (V_{RMS})	Measurement Uncertainty (V_{RMS})
1	0, 1	50 kHz (full scale*, sine wave)	2.5	5	1.767767	5	$\varepsilon = V_{Measured} - V_{Expected}$	±0.015142	±0.011207	±0.0016
2			1.769	3.538	1.250782	5		±0.011007	±0.008105	±0.0013
3			1.252	2.504	0.885298	5		±0.008082	±0.005912	±0.0010
4			0.887	1.774	0.627204	0.5		±0.006018	±0.004363	±0.00088
5			0.627	1.254	0.443356	0.5		±0.004547	±0.003260	±0.00032
6			0.444	0.888	0.313955	0.5		±0.003512	±0.002484	±0.00024
7			0.314	0.628	0.222032	0.5		±0.002776	±0.001932	±0.00018
8			0.222	0.444	0.156978	0.5		±0.002256	±0.001542	±0.00014
9			0.157	0.314	0.111016	0.5		±0.001888	±0.001266	±0.00012
10			0.111	0.222	0.078489	0.5		±0.001628	±0.001071	±0.000097
11			0.079	0.158	0.055861	0.05		±0.001447	±0.000935	±0.000084
12			0.055	0.110	0.038891	0.05		±0.001311	±0.000833	±0.000037
13			0.039	0.078	0.027577	0.05		±0.001221	±0.000765	±0.000029
14			0.028	0.056	0.019799	0.05		±0.001158	±0.000719	±0.000024
15			0.019	0.038	0.013435	0.05		±0.001107	±0.000681	±0.000019
16			0.014	0.028	0.009899	0.05		±0.001079	±0.000659	±0.000017
17			0.009	0.018	0.006364	0.05		±0.001051	±0.000638	±0.000014
18			0.007	0.014	0.004950	0.05		±0.001040	±0.00630	±0.000013
19			0.004	0.008	0.002828	0.05		±0.001023	±0.000617	±0.000012
20			0.003	0.006	0.002121	0.05		±0.001017	±0.000613	±0.000011
21			0.002	0.004	0.001414	0.05		±0.001011	±0.000608	±0.000011
22			0.0018	0.0036	0.001273	0.05		±0.001010	±0.000608	±0.000011

* Full scale for waveform data amplitude is ±1.

Differential Main Path

1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3.
2. Configure the DMM according to Table 13 with the following characteristics:
   - Function: AC voltage
   - Input impedance: 10 MΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 13, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Frequency: 50 kHz
   - Sample rate: 400 MS/s
   - Load impedance: 10 MΩ
   - Terminal configuration: Differential
4. Wait 15 seconds for the output of the NI 5451 to settle.
5. Measure the output voltage amplitude with the DMM.
6. Record the V_{RMS} measurement.
7. Calculate the RMS amplitude error using the equation in Table 13.
8. Compare the output error to the test limit for the appropriate configuration in Table 13.
9. Repeat steps 2 through 8 for each configuration in Table 13.
10. Set the output voltage level to 0.
11. Connect the differential CH 1 on the NI 5451 to the DMM, as shown in Figure 3.
12. Repeat steps 2 through 10 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 13.

Table 13. Differential Main Path AC Voltage Amplitude Absolute Accuracy Verification

Config.	CH	Waveform Data Amplitude	Gain	Differential Output Range ($V_{pk\text{-}pk}$)	Expected (V_{RMS})	DMM Range	Error (V)	As Found Test Limit (V_{RMS})	After Adjustment Test Limit (V_{RMS})	Measurement Uncertainty (V_{RMS})
1	0, 1	50 kHz (full scale*, sine wave)	5	10	3.535534	5	$\varepsilon = V_{Measured} - V_{Expected}$	±0.029784	±0.022013	±0.0026
2			3.539	7.078	2.502451	5		±0.021520	±0.015815	±0.0020
3			2.505	5.010	1.771302	5		±0.015670	±0.011428	±0.0016
4			1.774	3.548	1.254407	0.5		±0.011535	±0.008326	±0.0013
5			1.255	2.510	0.887419	0.5		±0.008599	±0.006125	±0.0010
6			0.889	1.778	0.628618	0.5		±0.006529	±0.004572	±0.00088
7			0.629	1.258	0.444770	0.5		±0.005058	±0.003469	±0.00032
8			0.445	0.890	0.314663	0.5		±0.004017	±0.002688	±0.00024
9			0.315	0.630	0.222739	0.5		±0.003282	±0.002136	±0.00018
10			0.223	0.446	0.157685	0.5		±0.002761	±0.001746	±0.00015
11			0.158	0.316	0.111723	0.05		±0.002394	±0.001470	±0.00012
12			0.111	0.222	0.078489	0.05		±0.002128	±0.001271	±0.000097
13			0.079	0.158	0.055861	0.05		±0.001947	±0.001135	±0.000084
14			0.056	0.112	0.039598	0.05		±0.001817	±0.001038	±0.000038
15			0.039	0.078	0.027577	0.05		±0.001721	±0.000965	±0.000029
16			0.028	0.056	0.019799	0.05		±0.001658	±0.000919	±0.000024
17			0.019	0.038	0.013435	0.05		±0.001607	±0.000881	±0.000019
18			0.014	0.028	0.009899	0.05		±0.001579	±0.000859	±0.000017
19			0.009	0.018	0.006364	0.05		±0.001551	±0.000838	±0.000014
20			0.007	0.014	0.004950	0.05		±0.001540	±0.000830	±0.000013
21			0.005	0.010	0.003536	0.05		±0.001528	±0.000821	±0.000012
22			0.0036	0.0072	0.002546	0.05		±0.001520	±0.000815	±0.000012

* Full scale for waveform data amplitude is ±1.

Differential Direct Path

1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3.
2. Configure the DMM with the following characteristics:
   - Function: AC voltage
   - Range: 5 V
   - Input impedance: 10 MΩ
   - Average reading: 4

Note These values assume you are using an NI 4071 DMM. For other DMMs, use the range closest to the values listed. The input impedance should be equal to or greater than the values indicated in Table 1.

3. Configure the NI 5451 according to Table 14, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Frequency: 50 kHz
   - Gain: 1
   - Sample rate: 400 MS/s
   - Load impedance: 10 MΩ
   - Terminal configuration: Differential
4. Wait 15 seconds for the output of the NI 5451 to settle.
5. Measure the output voltage amplitude with the DMM.
6. Record the V_{RMS} measurement.
7. Calculate the percent amplitude error using the equation in Table 14.
8. Compare the output error to the test limit for the appropriate configuration in Table 14.
9. Set the output voltage level to 0.
10. Connect the differential CH 1 on the NI 5451 to the DMM, as shown in Figure 3.
11. Repeat steps 3 through 9 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 14.

Table 14. Differential Direct Path AC Voltage Amplitude Absolute Accuracy Verification

CH	Waveform Data Amplitude	Gain	Differential Output Range	Error (%)	As Found Test Limit (%)	After Adjustment Test Limit (%)	Measurement Uncertainty (%)
0, 1	50 kHz (full scale*, sine wave)	1	2 V_{pk-pk}	$\varepsilon = (\sqrt{2} \times V_{RMS} - 1) \times 100$	±0.5	±0.2	±0.13

* Full scale for waveform data amplitude is ±1.

Verifying Differential Direct Path AC Voltage Amplitude Channel-to-Channel Relative Accuracy

Complete the following steps to verify the AC voltage amplitude channel-to-channel relative accuracy of an NI 5451 module.

1. Use the values recorded in step 6 of the *Differential Direct Path* subsection of the *Verifying AC Voltage Amplitude Absolute Accuracy* section to calculate the AC amplitude channel-to-channel relative accuracy using the equation in Table 15.
2. Compare the error to the test limit in Table 15.
3. Repeat steps 1 and 2 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 15.

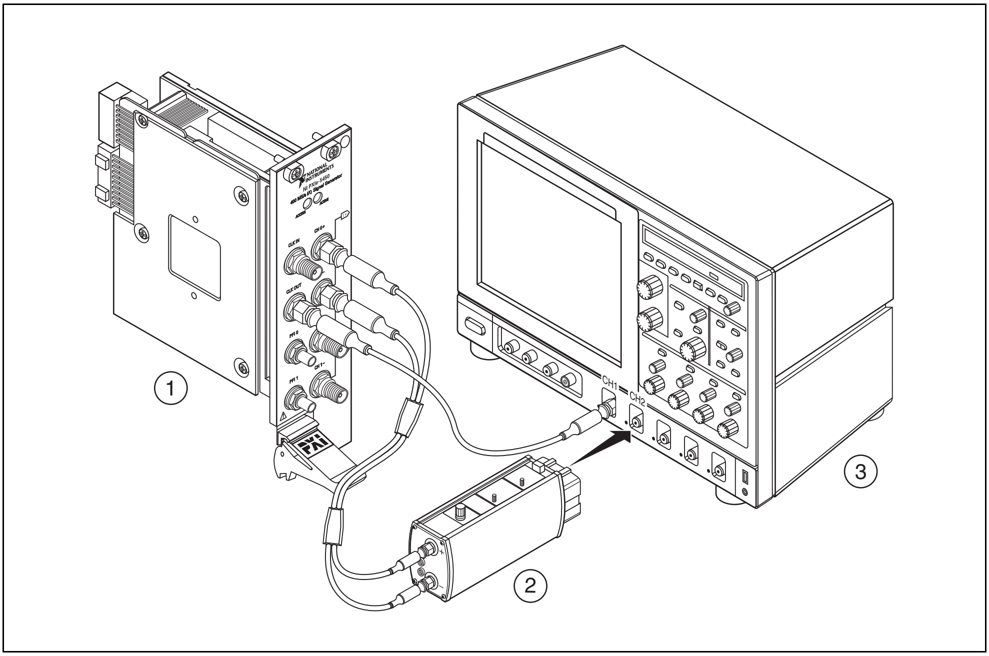
Table 15. Differential Direct Path AC Amplitude Channel-to-Channel Relative Accuracy Verification

CH	Analog Path	Gain	Differential Output Range (V_{pk-pk})	Error (mV_{pk-pk})	Test Limit (mV_{pk-pk})	Measurement Uncertainty (mV_{pk-pk})
0, 1	Direct	1	2.0	$\varepsilon_{0,1} = 2 \times \sqrt{2} \times (V_{RMS_{CH0}} - V_{RMS_{CH1}})$	±4.0	±0.2

Verifying Channel-to-Channel Timing Alignment Accuracy

Complete the following steps to verify the channel-to-channel timing alignment accuracy of an NI 5451 module using a digital oscilloscope and a differential acquisition probe.

1. Connect the devices as shown in Figure 7.



1 NI 5451	3 Tektronix DPO70404 Digital Oscilloscope
2 Tektronix P7380SMA Differential Probe	

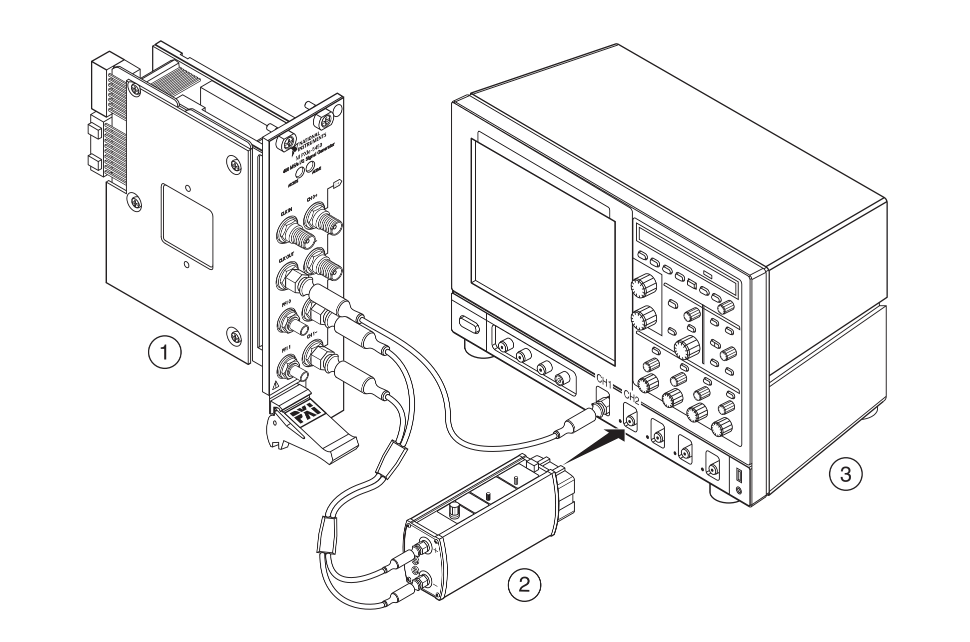
Figure 7. NI 5451 Connection to an Oscilloscope Using a Differential Acquisition Probe (CH 0)

Note Use the cables that are included with the differential probe for the connections to the NI 5451. When changing the connections from CH 0 to CH 1, maintain the same relative cable position.

2. Configure the NI 5451 according to Table 16, and generate a waveform with the following characteristics:
   - Waveform: Square wave
   - Waveform data amplitude: 0 dBFS
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω
   - Exported sample clock timebase divisor: 40
   - Sample clock timebase export location: Clkout
   - Terminal configuration: Differential

Note Both NI 5451 channels must be enabled simultaneously during this test. If the session is disabled or restarted at any point during the test, the measurements are invalid.

3. Configure the oscilloscope.
   a. Run DEFAULT SETUP to set the oscilloscope to a known state.
   b. Enable CH 1 and CH 2 on the oscilloscope.
   c. Run AUTOSET to acquire CH 1 and CH 2 waveforms.
   d. Set the oscilloscope to trigger continuously on the rising edge of CH 1.
   e. Set the acquisition mode to average 256 samples.
   f. Center the rising edge of the CH 2 waveform in the center of the oscilloscope display by using HORIZONTAL DELAY.
   g. Adjust the oscilloscope vertical scale of CH 2 to maximum while keeping the waveform within the display, approximately 125 mV/div.
   h. Set the timebase to 1 ns/div and use HORIZONTAL DELAY to keep the CH 2 rising edge centered in the oscilloscope display.
   i. Set the scale resolution to 1 ps/pt.
   j. Clear the acquisition averages and then wait for 256 acquisitions to occur.
   k. Save the CH 2 waveform as REF1 (NI 5451, CH 0).
4. Connect the devices as shown in Figure 8.



1	NI 5451	3	Tektronix DPO70404 Digital Oscilloscope
2	Tektronix P7380SMA Differential Probe		

Figure 8. NI 5451 Connection to an Oscilloscope Using a Differential Acquisition Probe (CH 1)

5. Clear the waveform averages. The rising edge of the NI 5451 CH 1 output waveform should now be in the center of the oscilloscope display.
6. Recall the CH 2 output waveform previously saved as REF1 (NI 5451, CH 0) in step 3.

7. Set the oscilloscope to measure the delay between REF1 (NI 5451, CH 0) and the current CH 2 input (NI 5451, CH 1). The measurement should be rising to rising edge at 50% amplitude.
8. Wait for the measurement counter to reach at least 50 before making the reading.
9. Measure and record the mean value.
10. Compare the delay value with the test limit in Table 16.
11. Repeat steps 3 through 10 using the next configuration in Table 16.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 16.

Table 16. Channel-to-Channel Timing Alignment Accuracy Verification

Config.	Analog Path	CH*	Output Frequency (MHz)	Channel-to-Channel Timing Alignment (ps)	Test Limit (ps)	Measurement Uncertainty (ps)
0	Main	0, 1	10	$t_{alignment} = \lvert t_{CH2} - t_{CH1} \rvert$	≤50	5.3
1	Direct		10		≤35	5.3

* Both NI 5451 channels must be enabled simultaneously during this test. If the session is disabled or restarted at any point during the test, the measurements are invalid.

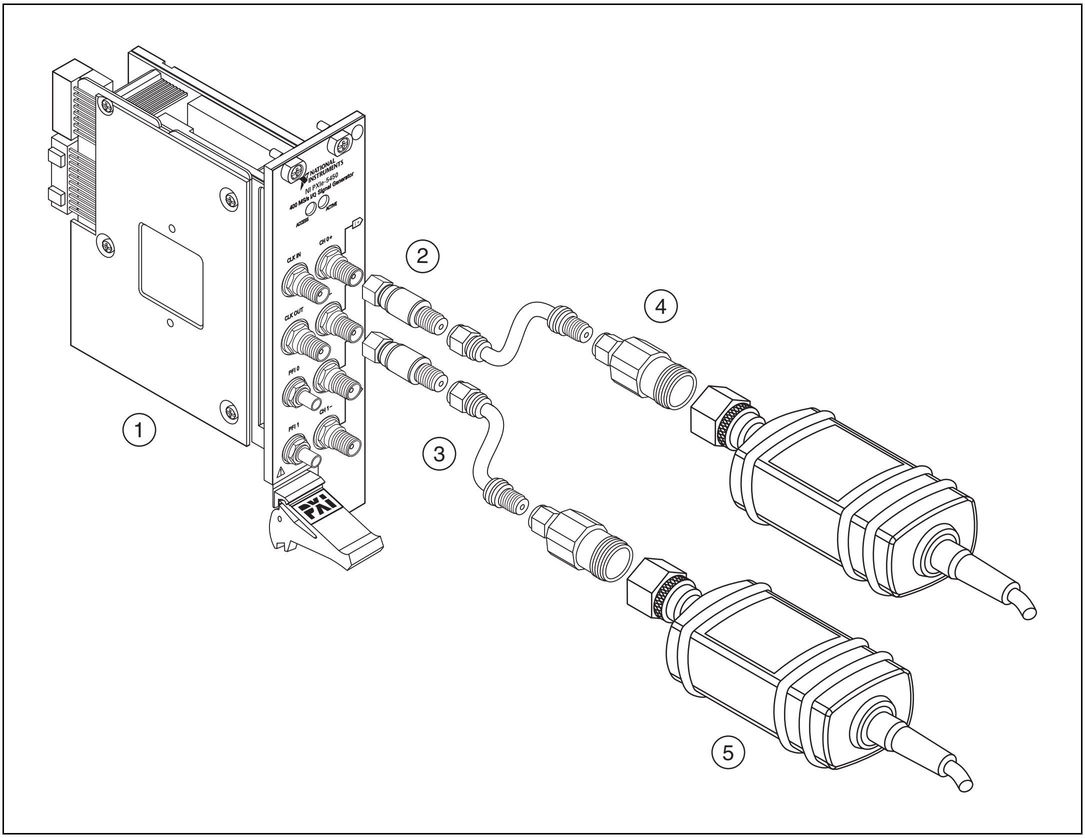
Verifying Frequency Response (Flatness)

Complete the following steps to verify the frequency response (flatness) of an NI 5451 module using a power meter(s) and 7 dB attenuators.

Note The frequency response (flatness) verification can be performed using a single power meter. If you are using a single power meter, load the unused terminal with the 7 dB attenuator and the 50 Ω termination.

Main Path (Single-Ended and Differential)

1. Connect the devices as shown in Figure 9, using semi-rigid coaxial cables to connect the power meters simultaneously if necessary.



1	NI 5451 Signal Generator	4	Type N to SMA adapter
2	Mini-Circuits VAT-7-1+ Attenuator	5	Rohde & Schwarz NRP-Z91 Power Meter
3	Anritsu K120MF-5CM semi-rigid coaxial cable		

Figure 9. NI 5451 Connection to Power Meters Using Attenuators (CH 0)

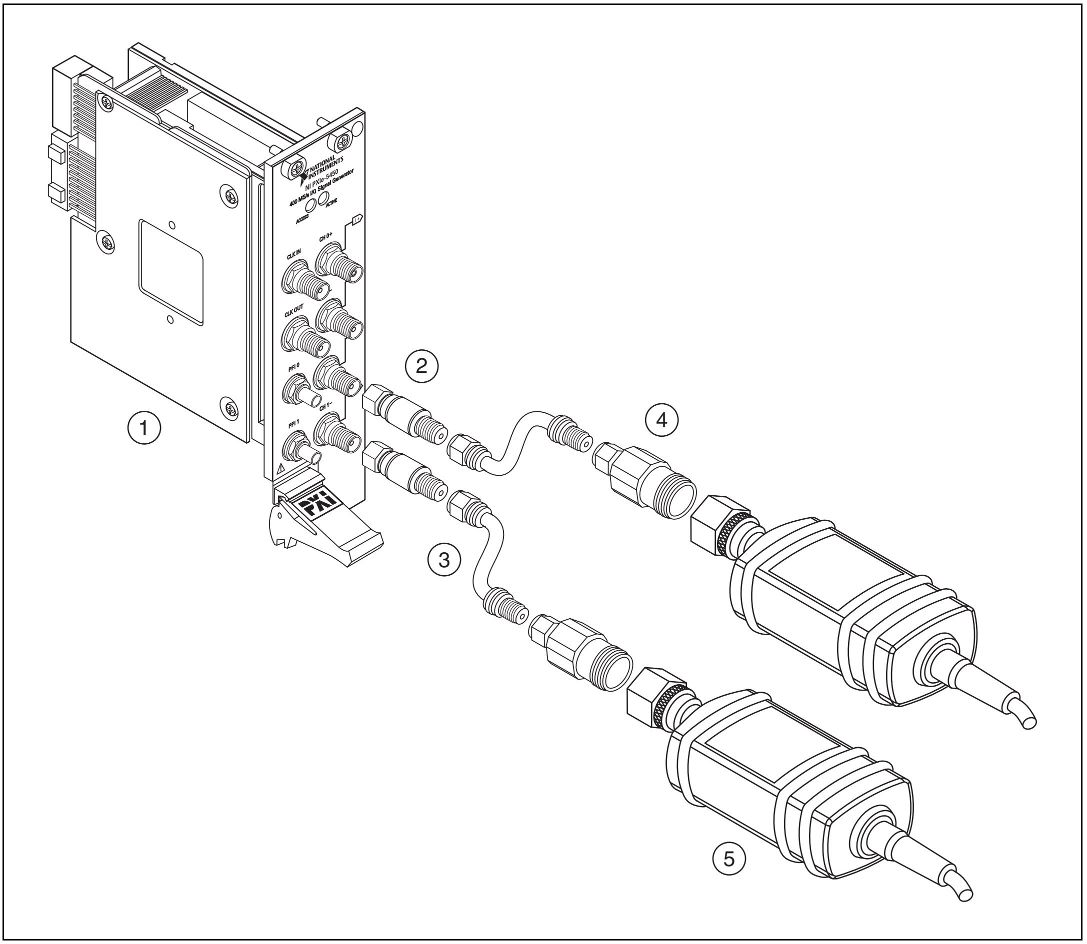
2. Disable the NI 5451 outputs, and then null the power meter(s) according to the power meter documentation.
3. Configure the power meter(s) according to Table 18 and the following characteristics:
   - Multichannel
   - Average: 16
   - Measure watts
   - Channel 1 power sensor connected to NI 5451(+)
   - Channel 2 power sensor connected to NI 5451(–)
   - High accuracy

4. Configure the NI 5451 according to Table 17 and Table 18, and generate a waveform with the following characteristics:
   - Waveform: Sine
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Flatness correction: Enabled
   - Terminal configuration: Differential
5. Allow the power meter to stabilize for 10 seconds.
6. Measure and record the reference (50 kHz) power ($W_{Ref(+)}$ [W]) of the positive output.
7. Measure and record the reference (50 kHz) power ($W_{Ref(-)}$ [W]) of the negative output.
8. Configure the power meter and the NI 5451 frequency according to the next configuration in Table 18.
9. Allow the power meter to stabilize for 10 seconds.
10. Measure and record the power at the set frequency ($W_{f(+)}$ [W]) of the positive output.
11. Measure and record the power at the set frequency ($W_{f(-)}$ [W]) of the negative output.
12. Calculate the *Frequency Response (Flatness)*, the deviation from the reference (50 kHz) power, using the appropriate equation in Table 18 and compare it to the test limit.
13. Repeat steps 8 through 12 for all frequencies in Table 18.
14. Configure the NI 5451 according to the next configuration in Table 17, and repeat steps 5 through 13 for configurations 0 to 5.

Table 17. Main Path Frequency Response (Flatness) Configuration

Config.	CH	Gain	Waveform Amplitude (dBFS)
0	0	1.75	0
1	0	1.75	–20
2	0	0.6209	0
3	0	0.6209	–20
4	0	0.03918	0
5	0	0.03918	–20
6	1	1.75	0
7	1	1.75	–20
8	1	0.6209	0
9	1	0.6209	–20
10	1	0.03918	0
11	1	0.03918	–20

15. Connect the devices as shown in Figure 10, using semi-rigid coaxial cables to connect the power meters simultaneously if necessary.



1	NI 5451 Signal Generator	4	Type N to SMA adapter
2	Mini-Circuits VAT-7-1+ Attenuator	5	Rohde & Schwarz NRP-Z91 Power Meter
3	Anritsu K120MF-5CM semi-rigid coaxial cable		

Figure 10. NI 5451 Connection to Power Meters Using Attenuators (CH 1)

16. Repeat steps 3 through 13 for configurations 6 to 11 in Table 17.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 18.

Table 18. Main Path Frequency Response (Flatness) Verification

Config.	CH	Frequency	Frequency Response (Flatness)*	As Found Test Limit (dB)	After Adjustment Test Limit (dB)	Measurement Uncertainty (dB)
1	0, 1	50 kHz	Single-Ended Main Path: $Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)}}{W_{Ref(+)}}\right]$ Differential Main Path: $Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)} + W_{f(-)} + 2 \times \sqrt{W_{f(+)} \times W_{f(-)}}}{W_{Ref(+)} + W_{Ref(-)} + 2 \times \sqrt{W_{Ref(+)} \times W_{Ref(-)}}}\right]$	REF	REF	—
2		10 kHz		±0.30	±0.270	0.10
3		100 kHz		±0.30	±0.270	0.10
4		1 MHz		±0.30	±0.270	0.10
5		10 MHz		±0.30	±0.270	0.10
6		20 MHz		±0.30	±0.270	0.10
7		30 MHz		±0.30	±0.270	0.10
8		40 MHz		±0.30	±0.270	0.10
9		50 MHz		±0.30	±0.270	0.10
10		60 MHz		±0.30	±0.270	0.10
11		70 MHz		±0.50	±0.39	0.12
12		80 MHz		±0.50	±0.39	0.12
13		90 MHz		±0.50	±0.39	0.12
14		100 MHz		±0.50	±0.39	0.12
15		110 MHz		±0.50	±0.39	0.12
16		120 MHz		±0.50	±0.39	0.12
17		130 MHz		±0.50	±0.39	0.12
18		135 MHz		±0.50	±0.39	0.12

* The differential equation converts the power meter readings in watts to voltage to add the differential amplitudes in volts, and then converts the result to dB.

Differential Direct Path

1. Connect the devices as shown in Figure 9, using semi-rigid coaxial cables to connect the power meters simultaneously if necessary.
2. Disable the NI 5451 outputs, and then null the power meter(s) according to the power meter documentation.
3. Configure the power meter(s) according to Table 19 and the following characteristics:
   - Multichannel
   - Average: 16
   - Measure watts
   - Channel 1 power sensor connected to NI 5451(+)
   - Channel 2 power sensor connected to NI 5451(–)
   - High accuracy
4. Configure the NI 5451 according to Table 19, and generate a waveform with the following characteristics:
   - Channel: CH 0
   - Waveform: Sine
   - Waveform data amplitude: 0 dBFS
   - Gain: 0.4
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Flatness correction: Enabled
   - Terminal configuration: Differential
5. Allow the power meter to stabilize for 10 seconds.
6. Measure and record the reference (50 kHz) power ($W_{Ref(+)}$ [W]) of the positive output.
7. Measure and record the reference (50 kHz) power ($W_{Ref(-)}$ [W]) of the negative output.
8. Configure the power meter and the NI 5451 frequency according to the next configuration in Table 19.
9. Allow the power meter to stabilize for 10 seconds.
10. Measure and record the power at the set frequency ($W_{f(+)}$ [W]) of the positive output.
11. Measure and record the power at the set frequency ($W_{f(-)}$ [W]) of the negative output.
12. Calculate the *Frequency Response (Flatness)*, the deviation from the reference (50 kHz) power, using the equation in Table 19 and compare it to the test limit.
13. Repeat steps 8 through 12 for each configuration in Table 19.
14. Set the waveform data amplitude to –20 dBFS on the NI 5451, and repeat steps 5 through 13.
15. Connect the devices as shown in Figure 10, using semi-rigid coaxial cables to connect the power meters simultaneously if necessary.
16. Set the waveform data amplitude to 0 dBFS on the NI 5451, and repeat steps 5 through 15 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 19.

Table 19. Differential Direct Path Frequency Response (Flatness) Verification

Config.	CH	Frequency	Frequency Response (Flatness)*	As Found Test Limit (dB)	After Adjustment Test Limit (dB)	Measurement Uncertainty (dB)
1	0, 1	50 kHz	$Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)} + W_{f(-)} + 2 \times \sqrt{W_{f(+)} \times W_{f(-)}}}{W_{Ref(+)} + W_{Ref(-)} + 2 \times \sqrt{W_{Ref(+)} \times W_{Ref(-)}}}\right]$	REF	REF	—
2		10 kHz		±0.24	±0.125	0.10
3		100 kHz		±0.24	±0.125	0.10
4		1 MHz		±0.24	±0.125	0.10
5		10 MHz		±0.24	±0.125	0.10
6		20 MHz		±0.24	±0.125	0.10
7		30 MHz		±0.24	±0.125	0.10
8		40 MHz		±0.24	±0.125	0.10
9		50 MHz		±0.24	±0.125	0.10
10		60 MHz		±0.24	±0.125	0.10
11		70 MHz		±0.34	±0.19	0.12
12		80 MHz		±0.34	±0.19	0.12
13		90 MHz		±0.34	±0.19	0.12
14		100 MHz		±0.34	±0.19	0.12
15		110 MHz		±0.34	±0.19	0.12
16		120 MHz		±0.34	±0.19	0.12

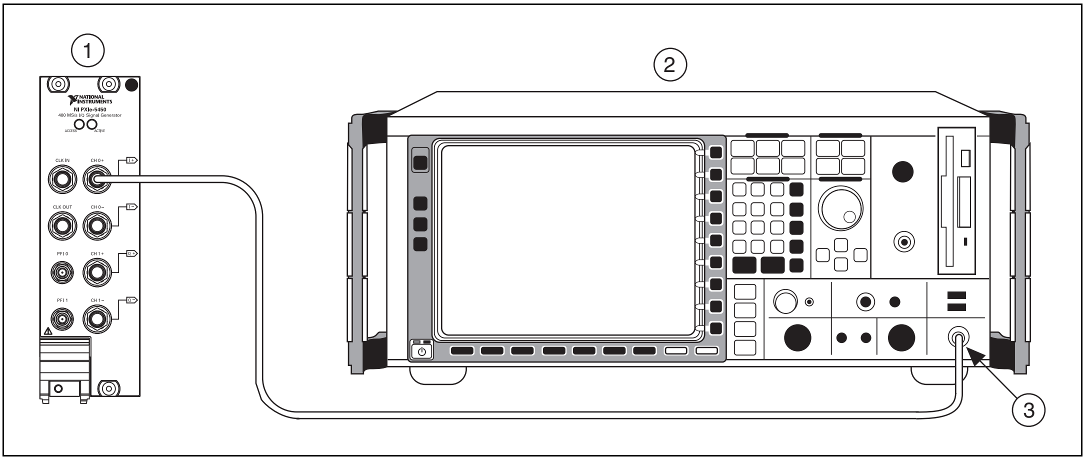
* This equation converts the power meter readings in watts to voltage to add the differential amplitudes in volts, and then converts the result to dB.

Verifying Average Noise Density

Complete the following steps to verify the average noise density of an NI 5451 module using a spectrum analyzer and, if required, a BALUN.

Single-Ended Main Path

1. Connect positive CH 0 to the spectrum analyzer, as shown in Figure 11.



1	NI 5451 signal generator	3	RF IN connector
2	R&S FSU26 spectrum analyzer		

Figure 11. NI 5451 Connection to Spectrum Analyzer (CH 0)

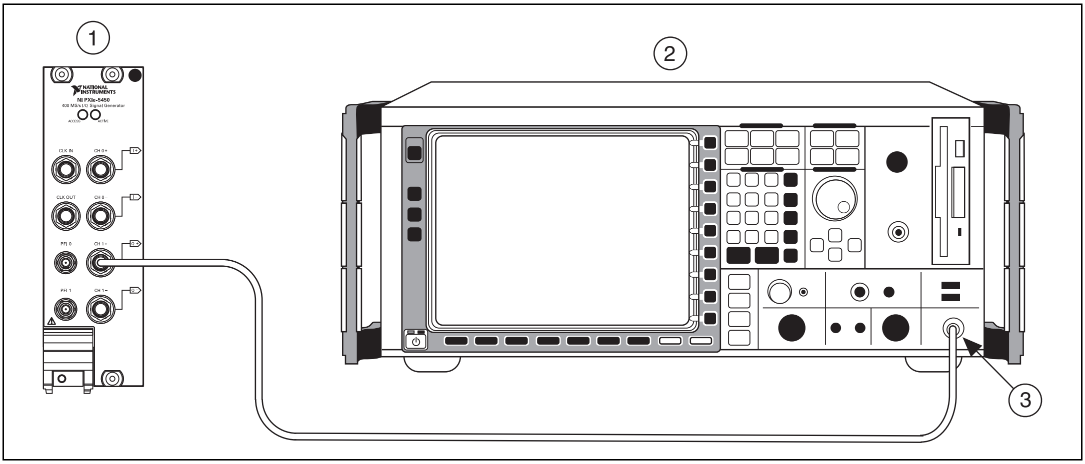
Note Use high quality 50 Ω SMA cables. Keep the cables as short as possible.

2. Set the spectrum analyzer to its default, and configure it according to Table 20 and the following characteristics:
   - Measurement: Noise marker on
   - Detector: RMS
   - Frequency range: 9 kHz to 200 MHz
   - Attenuation: 0 dB
   - Resolution bandwidth: 500 kHz
   - Video bandwidth: 2 MHz
   - Sweep time: 1 s
   - Preamplifier: On
3. Configure the NI 5451 according to Table 20, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: –40 dBFS
   - Frequency: 1 MHz
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω
   - Terminal configuration: Single ended

4. Set the marker frequency to 10 MHz.
5. Measure and record the noise density as displayed on MARKER1.

Note The marker should return the noise level in dBm/Hz.

6. With the focus on MARKER1 and using a step of 10 MHz, enter the new frequency.
7. Measure and record the noise density as displayed on MARKER1.
8. Repeat steps 5 through 7 until the frequency reaches 200 MHz.
9. Using the recorded power values, calculate the average noise density using the equation in Table 20.
10. Compare the Average Noise Density with the test limit in Table 20.
11. Repeat steps 3 through 10 for each gain in Table 20.
12. Connect positive CH 1 to the spectrum analyzer, as shown in Figure 12.



1	NI 5451 signal generator	3	RF IN connector
2	R&S FSU26 spectrum analyzer		

Figure 12. NI 5451 Connection to Spectrum Analyzer (CH 1)

13. Repeat steps 3 through 11 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 20.

Table 20. Single-Ended Main Path Average Noise Density Verification

CH	Output Frequency (MHz)	Gain	Reference Level (dBm)	Average Noise Density (dBm/Hz)	Test Limit (dBm/Hz)	Measurement Uncertainty (dB)
0, 1	0 to 200	1.25	–30	$AVG\_ND = 20 \times \log_{10}\left(\frac{\sum_{i=1}^{n} 10^{\left(\frac{NoiseDensity(i)}{20}\right)}}{n}\right)$ Frequency step = 10 MHz, from 10 MHz to 200 MHz	≤–145	±0.60
		0.25	–40		≤–147	±0.60
		0.03	–60		≤–147	±0.60

Differential Main Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.
2. Set the spectrum analyzer to its default, and configure it according to Table 21 and the following characteristics:
   - Measurement: Noise marker on
   - Detector: RMS
   - Frequency range: 9 kHz to 200 MHz
   - Attenuation: 0 dB
   - Resolution bandwidth: 500 kHz
   - Video bandwidth: 2 MHz
   - Sweep time: 1 s
   - Preamplifier: On
3. Configure the NI 5451 according to Table 21, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: –40 dBFS
   - Frequency: 1 MHz
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Terminal configuration: Differential
4. Set the marker frequency to 10 MHz.
5. Measure and record the noise density as displayed on MARKER1.

Note The marker should return the noise level in dBm/Hz.

6. With the focus on MARKER1 and using a step of 10 MHz, enter the new frequency.
7. Measure and record the noise density as displayed on MARKER1.
8. Repeat steps 6 and 7 until the frequency reaches 200 MHz.
9. Using the recorded power values, calculate the average noise density using the equation in Table 21.
10. Compare the Average Noise Density with the test limit in Table 21.
11. Repeat steps 3 through 10 for each gain in Table 21.
12. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14.
13. Repeat steps 3 through 11 for CH 1.

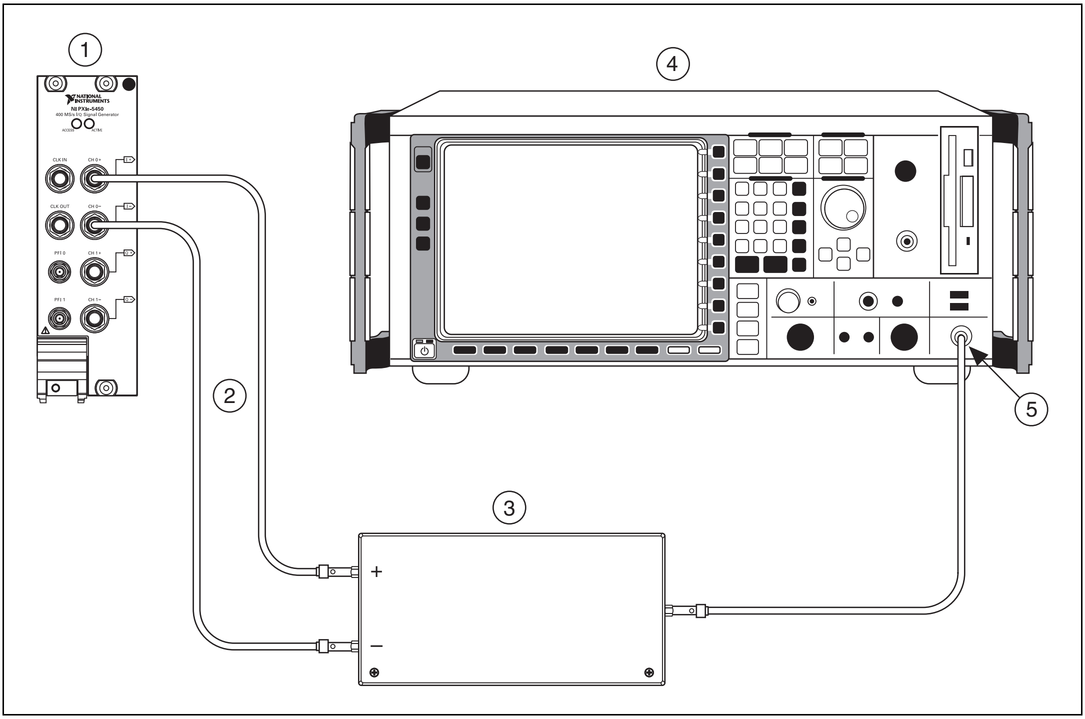
Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 21.

Table 21. Differential Main Path Average Noise Density Verification

CH	Output Frequency (MHz)	Gain	Reference Level (dBm)	Average Noise Density (dBm/Hz)	Test Limit (dBm/Hz)	Measurement Uncertainty (dB)
0, 1	0 to 200	2.5	–25	$AVG\_ND = 20 \times \log_{10}\left(\frac{\sum_{i=1}^{n} 10^{\langle\frac{NoiseDensity(i)}{20}\rangle}}{n}\right)$ Frequency step = 10 MHz, from 10 MHz to 200 MHz	≤–142	±0.60
		0.5	–40		≤–144	±0.60
		0.06	–60		≤–144	±0.60

Differential Direct Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.



1	NI 5451 signal generator	3	Picosecond 5320B BALUN	5	RF IN connector
2	Matched length cables	4	R&S FSU26 spectrum analyzer		

Figure 13. NI 5451 Connection to Spectrum Analyzer Using a BALUN (CH 0)

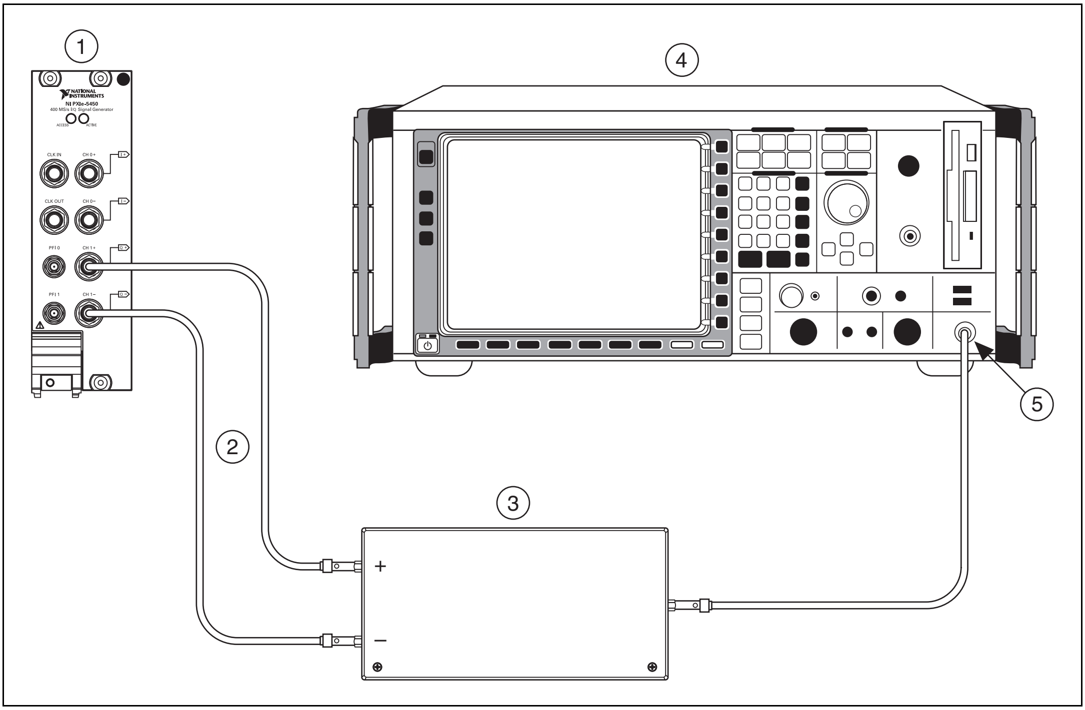
Note Use high quality 50 Ω SMA cables of the same electrical length. Keep the cables as short as possible for all connections.

2. Set the spectrum analyzer to its default, and configure it with the following characteristics:
   - Measurement: Noise marker on
   - Detector: RMS
   - Frequency range: 9 kHz to 200 MHz
   - Reference level: –40 dBm
   - Attenuation: 0 dB
   - Resolution bandwidth: 500 kHz
   - Video bandwidth: 2 MHz
   - Sweep time: 1 s
   - Preamplifier: On
3. Configure the NI 5451 according to Table 22, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: –40 dBFS
   - Frequency: 1 MHz
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Terminal configuration: Differential
4. Set the marker frequency to 10 MHz.
5. Measure and record the noise density as displayed on MARKER1.

Note The marker should return the noise level in dBm/Hz.

6. With the focus on MARKER1 and using a step of 10 MHz, enter the new frequency.
7. Measure and record the noise density as displayed on MARKER1.
8. Repeat steps 5 through 7 until the frequency reaches 200 MHz.
9. Using the recorded power values, calculate the average noise density using the equation in Table 22.
10. Compare the Average Noise Density with the test limit in Table 22.

11. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14.



1	NI 5451 signal generator	3	Picosecond 5320B BALUN	5	RF IN connector
2	Matched length cables	4	R&S FSU26 spectrum analyzer		

Figure 14. NI 5451 Connection to Spectrum Analyzer Using a BALUN (CH 1)

12. Repeat steps 3 through 10 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 22.

Table 22. Differential Direct Path Average Noise Density Verification

CH	Output Frequency (MHz)	Average Noise Density (dBm/Hz)	Test Limit (dBm/Hz)	Measurement Uncertainty (dB)
0, 1	0 to 200	$AVG\_ND = 20 \times \log_{10}\left(\frac{\sum_{i=1}^{n} 10^{\left\langle \frac{NoiseDensity(i)}{20} \right\rangle}}{n}\right)$ Frequency step = 10 MHz, from 10 MHz to 200 MHz	≤–160	±0.60

Verifying Internal Reference Clock Frequency Accuracy

Complete the following steps to verify the internal reference clock frequency accuracy of an NI 5451 module using a spectrum analyzer and BALUN.

Note You can also verify the internal reference clock frequency accuracy without a BALUN using single-ended Main path, as shown in Figure 11.

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.
2. Verify that the NI 5451 is not locked to an external clock and is using the onboard clock.
3. Set the spectrum analyzer to its default, and configure it with the following characteristics:
   - Frequency: 10 MHz
   - Span: 1 MHz
   - Reference level: 0 dBm
   - Measurement counter: 1 Hz
   - Signal count: Enabled
4. Configure the NI 5451, and generate a waveform with the following characteristics:
   - Channel: CH 0
   - Waveform: Sine wave
   - Waveform data amplitude: 0 dBFS
   - Frequency: 10 MHz
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Terminal configuration: Differential
5. Measure and record the frequency (f_{meas}) as displayed on MARKER1.
6. Compare the frequency measured with the test limit in Table 23.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 23.

Table 23. Internal Reference Clock Accuracy Verification

CH	Frequency (MHz)	Error (%)	As Found Test Limit (%)	Measurement Uncertainty (µHz/Hz)
0	10	$\varepsilon = \frac{f_{meas} - 10M}{10\ M} \times 100$	±0.01	0.33

Optional Verification Tests

Verifying Channel-to-Channel Frequency Response (Flatness) Matching Accuracy

Complete the following steps to verify the channel-to-channel frequency response (flatness) matching accuracy of an NI 5451 module.

Single-Ended Main Path

1. Calculate the channel-to-channel frequency response (flatness) matching accuracy for each configuration in Table 24 using the values calculated in the *Verifying Frequency Response (Flatness)* section.
2. Compare the errors to the test limits in Table 24.
3. Repeat steps 1 and 2 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 24.

Table 24. Single-Ended Main Path Channel-to-Channel Frequency Response (Flatness) Matching Accuracy Verification

Config.	CH	Frequency	Error (dB)	Test Limit (dB), typical
1	0, 1	10 kHz	$\varepsilon_{(CH0-CH1)} = Flatness_{CH0(f)} - Flatness_{CH1(f)}$	±0.12
2		100 kHz		±0.12
3		1 MHz		±0.12
4		10 MHz		±0.12
5		20 MHz		±0.12
6		30 MHz		±0.12
7		40 MHz		±0.12
8		50 MHz		±0.12
9		60 MHz		±0.12
10		70 MHz		±0.14
11		80 MHz		±0.14
12		90 MHz		±0.14
13		100 MHz		±0.14
14		110 MHz		±0.14
15		120 MHz		±0.14
16		135 MHz		±0.14

Differential Main Path

1. Calculate the channel-to-channel frequency response (flatness) matching accuracy for each configuration in Table 25 using the values calculated in the *Verifying Frequency Response (Flatness)* section.
2. Compare the errors to the test limits in Table 25.
3. Repeat steps 1 and 2 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 25.

Table 25. Differential Main Path Channel-to-Channel Frequency Response (Flatness) Matching Accuracy Verification

Config.	CH	Frequency	Error (dB)	Test Limit (dB), typical
1	0, 1	10 kHz	$\varepsilon_{(CH0 - CH1)} = Flatness_{CH0(f)} - Flatness_{CH1(f)}$	±0.12
2		100 kHz		±0.12
3		1 MHz		±0.12
4		10 MHz		±0.12
5		20 MHz		±0.12
6		30 MHz		±0.12
7		40 MHz		±0.12
8		50 MHz		±0.12
9		60 MHz		±0.12
10		70 MHz		±0.14
11		80 MHz		±0.14
12		90 MHz		±0.14
13		100 MHz		±0.14
14		110 MHz		±0.14
15		120 MHz		±0.14
16		135 MHz		±0.14

Differential Direct Path

1. Calculate the channel-to-channel frequency response (flatness) matching accuracy for each configuration in Table 26 using the values calculated in the *Verifying Frequency Response (Flatness)* section.
2. Compare the errors to the test limits in Table 26.
3. Repeat steps 1 and 2 for CH 1.

Note Refer to the *Measurement Uncertainty* section for more information about the measurement uncertainty calculations in Table 26.

Table 26. Differential Direct Path Channel-to-Channel Frequency Response (Flatness) Matching Accuracy Verification

Config.	CH	Frequency	Error (dB)	Test Limit (dB), typical
1	0, 1	10 kHz	$\varepsilon_{(CH0-CH1)} = Flatness_{CH0(f)} - Flatness_{CH1(f)}$	±0.03
2		100 kHz		±0.03
3		1 MHz		±0.03
4		10 MHz		±0.03
5		20 MHz		±0.03
6		30 MHz		±0.03
7		40 MHz		±0.03
8		50 MHz		±0.03
9		60 MHz		±0.03
10		70 MHz		±0.04
11		80 MHz		±0.04
12		90 MHz		±0.04
13		100 MHz		±0.04
14		110 MHz		±0.04
15		120 MHz		±0.04

Verifying Analog Bandwidth

Complete the following steps to verify the analog bandwidth of an NI 5451 module using a power meter(s).

Note The analog bandwidth verification can be performed using a single power meter. If you are using a single power meter, load the unused terminal with the 7 dB attenuator and the 50 Ω termination.

Main Path

1. Connect the devices as shown in Figure 9, using semi-rigid coaxial cables to connect the power meters simultaneously if necessary.
2. Disable the NI 5451 outputs, and then null the power meter(s) according to the power meter documentation.
3. Configure the power meter(s) according to Table 27 and the following characteristics:
    - Multichannel
    - Average: 16
    - Measure watts
    - High accuracy

4. Configure the NI 5451 according to Table 27, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: 0 dBFS
   - Channel: CH 0
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Analog filter: Enabled
   - Flatness correction: Disabled
   - Terminal configuration: Differential
5. Allow the power meter to stabilize for 10 seconds.
6. Measure and record the reference power ($W_{Ref(+)}$ [W]) of the positive output.
7. Measure and record the reference power ($W_{Ref(-)}$ [W]) of the negative output.
8. Configure the power meter and the NI 5451 frequency according to the next configuration in Table 27.
9. Allow the power meter to stabilize for 10 seconds.
10. Measure and record the power at the set frequency ($W_{f(+)}$ [W]) of the positive output.
11. Measure and record the power at the set frequency ($W_{f(-)}$ [W]) of the negative output.
12. Using the recorded power values, calculate the deviation from the reference power using the equation in Table 27.
13. Compare the frequency response (flatness) to the test limit for the appropriate configuration in Table 27.
14. Repeat steps 8 through 13 for each configuration in Table 27.
15. Repeat steps 3 through 14 for CH 1.

Table 27. Main Path Analog Bandwidth Verification

Config.	CH	Frequency	Frequency Response*	Test Limit (dB), typical
1	0, 1	50 kHz	REF	—
2		130 MHz	Single-Ended Main Path: $Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)}}{W_{Ref(+)}}\right]$ Differential Main Path: $Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)} + W_{f(-)} + 2 \times \sqrt{W_{f(+)} \times W_{f(-)}}}{W_{Ref(+)} + W_{Ref(-)} + 2 \times \sqrt{W_{Ref(+)} \times W_{Ref(-)}}}\right]$	≥–2.825
3		135 MHz		≥–3

* The differential equation converts the power meter readings from watts to voltage to add the differential amplitudes in volts and then converts the result to dB.

Direct Path

Repeat steps 3 through 13 above for Direct path, replacing Table 27 with Table 28.

Table 28. Direct Path Analog Bandwidth Verification

Config.	CH	Frequency	Frequency Response*	Test Limit (dB), typical
1	0, 1	50 kHz	REF	—
2		130 MHz	$Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)} + W_{f(-)} + 2 \times \sqrt{W_{f(+)} \times W_{f(-)}}}{W_{Ref(+)} + W_{Ref(-)} + 2 \times \sqrt{W_{Ref(+)} \times W_{Ref(-)}}}\right]$	≥–2.25
3		140 MHz		≥–2.75
4		145 MHz		≥–3

* This equation converts the power meter readings from watts to voltage to add the differential amplitudes in volts and then converts the result to dB.

Verifying Spurious Free Dynamic Range (SFDR) with and without Harmonics

Complete the following steps to verify the spurious free dynamic range with and without harmonics of an NI 5451 module using a spectrum analyzer and BALUN.

Single-Ended Main Path

1. Connect positive CH 0 to the spectrum analyzer, as shown in Figure 11.
2. Configure the spectrum analyzer according to Table 29, and configure it with the following characteristics:
   - Reference level: 0 dBm
   - Detector mode: Max peak
   - Video bandwidth: 20 kHz
   - Averaging: On
   - Sweep count: 10
3. Configure the NI 5451 according to Table 29, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: –1 dBFS
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω
   - Terminal configuration: Single ended
4. Place MARKER1 at the carrier frequency and set it as a fixed reference.
5. Turn on MARKER2 as a delta marker.
6. Wait until the spectrum analyzer has reached sweep count.
7. Move MARKER2 to the highest peak within the 200 MHz range.
8. Measure and record the SFDR (with harmonics) as displayed by the delta marker.

Note The marker should return the measurement in dBc.

9. Compare the SFDR (with harmonics) with the test limit in Table 29.
10. Move Marker2 to the highest peak that is a non-harmonic of the carrier.

Note Aliased harmonics are considered non-harmonics. Harmonics are only integer multiples of the carrier frequency.

11. Measure and record the SFDR (without harmonics) as displayed on delta marker.
12. Compare the SFDR (without harmonics) with the test limit in Table 29.
13. Configure the NI 5451 output frequency (carrier) according to the next configuration in Table 29 for the specific gain, reset the average, and repeat steps 4 through 12.
14. Repeat steps 2 through 13 for all gains in Table 29.
15. Connect positive CH 1 to the spectrum analyzer, as shown in Figure 12.
16. Repeat steps 2 through 14 for CH 1.

Table 29. Single-Ended Main Path Spurious Free Dynamic Range Accuracy Verification

Config.	CH	Gain	Carrier Frequency (MHz)	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	0.25	10	30	5	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥73
2						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥74
3			60			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥65
4						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥72
5			100			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥53
6						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥66
7			120			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

Table 29. Single-Ended Main Path Spurious Free Dynamic Range Accuracy Verification (Continued)

Config.	CH	Gain	Carrier Frequency (MHz)	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	0.625	10	35	10	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥73
2						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥74
3			60			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥61
4						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥72
5			100			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥52
6						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥66
7			120			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

Table 29. Single-Ended Main Path Spurious Free Dynamic Range Accuracy Verification (Continued)

Config.	CH	Gain	Carrier Frequency (MHz)	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	1.25	10	45	15	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥73
2						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥74
3			60			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥56
4						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥72
5			100			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥49
6						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥66
7			120			$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8						$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

Differential Main Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.
2. Configure the spectrum analyzer according to Table 30, and configure it with the following characteristics:
    - Reference level: 0 dBm
    - Detector mode: Max peak
    - Video bandwidth: 20 kHz
    - Averaging: On
    - Sweep count: 10
3. Configure the NI 5451 according to Table 30, and generate a waveform with the following characteristics:
    - Waveform: Sine wave
    - Waveform data amplitude: –1 dBFS
    - Sample rate: 400 MS/s
    - Load impedance: 50 Ω
    - Terminal configuration: Differential
4. Place MARKER1 at the carrier frequency and set it as a fixed reference.
5. Turn on MARKER2 as a delta marker.
6. Wait until the spectrum analyzer has reached sweep count.
7. Move MARKER2 to the highest peak within the 200 MHz range.
8. Measure and record the SFDR (with harmonics) as displayed by the delta marker.

Note The marker should return the measurement in dBc.

9. Compare the SFDR (with harmonics) with the test limit in Table 30 for the carrier frequency.
10. Move Marker2 to the highest peak that is a non-harmonic of the carrier.

Note Aliased harmonics are considered non-harmonics. Harmonics are only integer multiples of the carrier frequency.

11. Measure and record the SFDR (without harmonics) as displayed on delta marker.
12. Compare the SFDR (without harmonics) with the test limit in Table 30 for the carrier frequency.
13. Configure the NI 5451 output frequency (carrier) according to the next configuration for the specific gain in Table 30, reset the average, and repeat steps 4 through 12.
14. Repeat steps 2 through 13 for all gains in Table 30.
15. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14.
16. Repeat steps 2 through 14 for CH 1.

Table 30. Differential Main Path Spurious Free Dynamic Range Accuracy Verification

Config.	CH	Gain	Carrier Frequency (MHz)	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	0.5	10	35	5	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥73
2				35		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥74
3			60	35		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥69
4				35		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥72
5			100	35		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥55
6				35		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥66
7			120	35		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8				35		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

Table 30. Differential Main Path Spurious Free Dynamic Range Accuracy Verification (Continued)

Config.	CH	Gain	Carrier Frequency (MHz)	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	1.25	10	40	10	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥73
2				40		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥74
3			60	40		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥67
4				40		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥72
5			100	40		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥54
6				40		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥66
7			120	40		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8				40		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

Table 30. Differential Main Path Spurious Free Dynamic Range Accuracy Verification (Continued)

Config.	CH	Gain	Carrier Frequency (MHz)	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	2.5	10	45	15	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥73
2				45		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥74
3			60	45		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥64
4				45		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥72
5			100	45		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥53
6				45		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥66
7			120	45		$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8				45		$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

Differential Direct Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.
2. Set the spectrum analyzer to its default, and configure it with the following characteristics:
   - Frequency range: 9 kHz to 210 MHz
   - Attenuation: 30 dB
   - Reference level: 0 dBm
   - Detector mode: Max peak
   - Resolution bandwidth: 5 kHz
   - Video bandwidth: 20 kHz
   - Averaging: On
   - Sweep count: 10
3. Configure the NI 5451 according to Table 31, and generate a waveform with the following characteristics:
   - Waveform data amplitude: –1 dBFS
   - Waveform: Sine wave
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Terminal configuration: Differential
4. Place MARKER1 at the carrier frequency and set it as a fixed reference.
5. Turn on MARKER2 as a delta marker.
6. Wait until the spectrum analyzer has reached sweep count.
7. Move MARKER2 to the highest peak within the 200 MHz range.
8. Measure and record the SFDR (with harmonics) as displayed by the delta marker.

   Note The marker should return the measurement in dBc.

9. Compare the SFDR (with harmonics) with the test limit in Table 31 for the carrier frequency.
10. Move Marker2 to the highest peak that is a non-harmonic of the carrier.

    Note Aliased harmonics are considered non-harmonics. Harmonics are only integer multiples of the carrier frequency.

11. Measure and record the SFDR (without harmonics) as displayed on delta marker.
12. Compare the SFDR (without harmonics) with the test limit in Table 31 for the carrier frequency.
13. Configure the NI 5451 output frequency (carrier) according to the next configuration in Table 31, reset the average, and repeat steps 4 through 12.
14. Repeat steps 4 through 13 for all configurations in Table 31.
15. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14.
16. Repeat steps 4 through 14 for CH 1.

Table 31. Differential Direct Path Spurious Free Dynamic Range Accuracy Verification

Config.	CH	Carrier Frequency (MHz)	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	10	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥73
2			$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥74
3		60	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥70
4			$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥72
5		100	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥60
6			$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥64
7		120	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8			$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62
9		160	$SFDR_{With\ Harmonics}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
10			$SFDR_{Without\ Harmonics}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

Verifying Total Harmonic Distortion (THD)

Complete the following steps to verify the total harmonic distortion of an NI 5451 module using a spectrum analyzer.

Single-Ended Main Path

1. Connect positive CH 0 to the spectrum analyzer, as shown in Figure 11.
2. Set the spectrum analyzer to its default, and configure it according to Table 32 and the following characteristics:
    - Detector mode: Max peak
    - Span: 100 kHz
    - Resolution bandwidth: 2 kHz
    - Video bandwidth: 5 kHz
    - Average: On
    - Sweep: 20

3. Configure the NI 5451 according to Table 32, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: –1 dBFS
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω
   - Terminal configuration: Single ended
4. Enable the HARMONIC DISTORTION measurement function.
5. Wait until the spectrum analyzer has acquired all sweeps to average.
6. Set the NO. OF HARMONICS to 6.
7. De-select the HARMONIC RBW AUTO function.
8. To further try to optimize the measurement, go to AMPT menu and change the RF ATTENUATION to minimize the spectrum analyzer distortion on the THD reading.

Note Incorrect attenuation on the spectrum analyzer can severely affect the THD measurement. Refer to the spectrum analyzer documentation for more information.

9. Record the THD value, and compare it with the test limit in Table 32 for the Carrier Frequency.
10. Disable the HARMONIC measure function.
11. Repeat steps 3 through 10 for all configurations in that specific gain in Table 32.
12. Repeat steps 2 through 11 for all gains in Table 32.
13. Connect positive CH 1 to the spectrum analyzer, as shown in Figure 12.
14. Repeat steps 2 through 12 for CH 1.

Table 32. Single-Ended Main Path Total Harmonic Distortion Accuracy Verification

Config.	CH	Gain	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Carrier Frequency (MHz)	Test Limit (dBc), typical
1	0, 1	0.25	30	0	10.1	–80
2					20.1	–74
3					40.1	–68
4					60.1	–64
5					80.1	–62
6					120.1	–65
7					140.1	–64
8					160.1	–61
1	0, 1	0.625	35	10	10.1	–78
2					20.1	–72
3					40.1	–63
4					60.1	–60
5					80.1	–56
6					120.1	–56
7					140.1	–56
8					160.1	–55
1	0, 1	1.25	45	15	10.1	–71
2					20.1	–66
3					40.1	–59
4					60.1	–55
5					80.1	–51
6					120.1	–50
7					140.1	–50
8					160.1	–50

Differential Main Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.
2. Set the spectrum analyzer to its default, and configure it according to Table 33 and the following characteristics:
   - Detector mode: Max peak
   - Span: 100 kHz
   - Resolution bandwidth: 2 kHz
   - Video bandwidth: 5 kHz
   - Average: On
   - Sweep: 20
3. Configure the NI 5451 according to Table 33, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: –1 dBFS
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω Differential)
   - Terminal configuration: Differential
4. Enable the HARMONIC DISTORTION measurement function.
5. Wait until the spectrum analyzer has acquired all sweeps to average.
6. Set the NO. OF HARMONICS to 6.
7. De-select the HARMONIC RBW AUTO function.
8. To further try to optimize the measurement, go to AMPT menu and change the RF ATTENUATION to minimize the spectrum analyzer distortion on the THD reading.

Note Incorrect attenuation on the spectrum analyzer can severely affect the THD measurement. Refer to the spectrum analyzer documentation for more information.

9. Record the THD value, and compare it with the test limit in Table 33 for the Carrier Frequency.
10. Disable the HARMONIC measure function.
11. Repeat steps 3 through 10 for all configurations of that specific gain in Table 33.
12. Repeat steps 2 through 11 for all gains in Table 33.
13. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14.
14. Repeat steps 2 through 12 for CH 1.

Table 33. Differential Main Path Total Harmonic Distortion Accuracy Verification

Config.	CH	Gain	Spectrum Analyzer Attenuation	Spectrum Analyzer Reference Level	Carrier Frequency (MHz)	Test Limit (dBc), typical
1	0, 1	0.5	40	0	10.1	–79
2					20.1	–75
3					40.1	–69
4					60.1	–69
5					80.1	–65
6					120.1	–70
7					140.1	–69
8					160.1	–66
1	0, 1	1.25	45	10	10.1	–75
2					20.1	–73
3					40.1	–69
4					60.1	–65
5					80.1	–59
6					120.1	–59
7					140.1	–59
8					160.1	–59
1	0, 1	2.5	50	15	10.1	–71
2					20.1	–69
3					40.1	–64
4					60.1	–61
5					80.1	–55
6					120.1	–51
7					140.1	–52
8					160.1	–53

Differential Direct Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.
2. Set the spectrum analyzer to its default, and configure it according to Table 34 and the following characteristics:
   - Reference level: 0 dBm
   - Attenuation: 35 dB
   - Detector mode: Max peak
   - Span: 100 kHz
   - Resolution bandwidth: 2 kHz
   - Video bandwidth: 5 kHz
   - Average: On
   - Sweep: 20
3. Configure the NI 5451 according to Table 34, and generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Waveform data amplitude: –1 dBFS
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Terminal configuration: Differential
4. Enable the HARMONIC DISTORTION measurement function.
5. Wait until the spectrum analyzer has acquired all sweeps to average.
6. Set the NO. OF HARMONICS to 6.
7. De-select the HARMONIC RBW AUTO function.
8. To further try to optimize the measurement, go to AMPT menu and change the RF ATTENUATION to minimize the spectrum analyzer distortion on the THD reading.

Note Incorrect attenuation on the spectrum analyzer can severely affect the THD measurement. Refer to the spectrum analyzer documentation for more information.

9. Record the THD value, and compare it with the test limit in Table 34 for the Carrier Frequency.
10. Disable the HARMONIC measure function.
11. Repeat steps 2 through 10 for each configuration in Table 34.
12. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14.
13. Repeat steps 2 through 11 for CH 1.

Table 34. Differential Direct Path Total Harmonic Distortion Accuracy Verification

Config.	CH	Carrier Frequency (MHz)	Test Limit (dBc), typical
1	0, 1	10.1	≤–75
2		20.1	≤–70
3		40.1	≤–68
4		80.1	≤–68
5		100.1	≤–68
6		120.1	≤–78
7		160.1	≤–83

Verifying Intermodulation Distortion (IMD_3)

Complete the following steps to verify the intermodulation distortion of an NI 5451 module using a 7 dB attenuator, a spectrum analyzer and, if required, a BALUN.

Single-Ended Main Path

1. Connect positive CH 0 to the spectrum analyzer, as shown in Figure 11. If necessary, insert a 7 dB attenuator inline. Refer to the note in Table 35 for more information.
2. Configure the spectrum analyzer according to Table 35 and the following characteristics:
    - Detector mode: Max peak
    - Span: 700 kHz
    - Resolution bandwidth: 5 kHz
    - Video bandwidth: 20 kHz
    - Average: On
    - Sweep: 50
3. Configure the NI 5451 according to Table 35, and generate a waveform with the following characteristics:
    - Sample rate: 400 MS/s
    - Waveform data amplitude (each tone): –7 dBFS
    - Load impedance: 50 Ω (100 Ω differential)
    - Terminal configuration: Single ended
4. Enable the TOI function.
5. To further try to optimize the measurement, go to the AMPT menu and change the RF ATTENUATION to minimize the spectrum analyzer distortion on the IMD_3 (TOI) reading.

Note Incorrect attenuation on the spectrum analyzer can severely affect the IMD_3 measurement. Refer to the spectrum analyzer documentation for more information.

6. Measure and record the value of the following:
    - Amplitude of Carrier Tone 1
    - Amplitude of Carrier tone 2
    - Amplitude of 3rd order harmonic product 1, $2f_2–f_1$
    - Amplitude of 3rd order harmonic product 2, $2f_1–f_2$

7. Use the equation in Table 35 to calculate the IMD_3, and compare it to the test limit in Table 35.
8. Configure the NI 5451 according to the next configuration in Table 35 for the specific gain.
9. Repeat steps 2 through 8 for all gains in Table 35.
10. Connect positive CH 1 to the spectrum analyzer, as shown in Figure 12. If necessary, insert a 7 dB attenuator inline. Refer to the note in Table 35 for more information.
11. Repeat steps 2 through 9 for CH 1.

Table 35. Single-Ended Main Path Intermodulation Distortion (IMD_3) Verification

Config.	CH	Gain	Tone 1 Frequency (MHz)	Tone 2 Frequency (MHz)	Center Frequency (MHz)	Spectrum Analyzer Attenuation (dB)	Spectrum Analyzer Reference Level (dBm)	IMD_3 (dBc)	Test Limit (dBc), typical
1	0, 1	0.05	9.9	10.1	10	0	–20		–89
2			19.9	20.1	20	0	–20		–83
3			39.9	40.1	40	0	–20		–78
4			59.9	60.1	60	0	–20	$Max(P_{\langle 2 \times f_2 - f_1 \rangle}, P_{\langle 2 \times f_1 - f_2 \rangle}) - Min(P_{f_1}, P_{f_2})$	–73
5			79.9	80.1	80	0	–20		–69
6			119.9	120.1	120	0	–20		–66
7			159.9	160.1	160	0	–20		–65
1	0, 1	0.25	9.9	10.1	10	20	–5		–87
2			19.9	20.1	20	20	–5		–85
3			39.9	40.1	40	20	–5		–82
4			59.9	60.1	60	20	–5	$Max(P_{\langle 2 \times f_2 - f_1 \rangle}, P_{\langle 2 \times f_1 - f_2 \rangle}) - Min(P_{f_1}, P_{f_2})$	–79
5			79.9	80.1	80	20	–5		–75
6			119.9	120.1	120	20	–5		–79
7			159.9	160.1	160	20	–5		–75

Table 35. Single-Ended Main Path Intermodulation Distortion (IMD_3) Verification (Continued)

Config.	CH	Gain	Tone 1 Frequency (MHz)	Tone 2 Frequency (MHz)	Center Frequency (MHz)	Spectrum Analyzer Attenuation (dB)	Spectrum Analyzer Reference Level (dBm)	IMD_3 (dBc)	Test Limit (dBc), typical
1	0, 1	0.625	9.9	10.1	10	30	5	$Max(P_{\langle 2\times f_2-f_1\rangle},P_{\langle 2\times f_1-f_2\rangle})-Min(P_{f_1},P_{f_2})$	–92
2			19.9	20.1	20	30	5		–87
3			39.9	40.1	40	30	5		–79
4			59.9	60.1	60	30	5		–72
5			79.9	80.1	80	30	5		–66
6			119.9	120.1	120	30	5		–61
7			159.9	160.1	160	30	5		–57
1	0, 1	1.25	9.9	10.1	10	30	10	$Max(P_{\langle 2\times f_2-f_1\rangle},P_{\langle 2\times f_1-f_2\rangle})-Min(P_{f_1},P_{f_2})$	–87
2			19.9	20.1	20	30	10		–82
3			39.9	40.1	40	30	10		–71
4			59.9	60.1	60	30	10		–63
5			79.9	80.1	80	30	10		–57
6			119.9	120.1	120	30	10		–51
7			159.9	160.1	160	30	10		–48

Note: You must add a 7 dB external attenuator for the 10 MHz and 20 MHz center frequency measurements for the 0.625 and 1.25 gains.

Differential Main Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13. If necessary, insert a 7 dB attenuator inline. Refer to the note in Table 36 for more information.
2. Configure the spectrum analyzer according to Table 36 and the following characteristics:
   - Detector mode: Max peak
   - Span: 700 kHz
   - Resolution bandwidth: 5 kHz
   - Video bandwidth: 20 kHz
   - Average: On
   - Sweep: 50
3. Configure the NI 5451 according to Table 36, and generate a waveform with the following characteristics:
   - Waveform data amplitude (each tone): –7 dBFS
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Terminal configuration: Differential
4. Enable the TOI function.
5. To further try to optimize the measurement, go to the AMPT menu and change the RF ATTENUATION to minimize the spectrum analyzer distortion on the IMD_3 (TOI) reading.

Note Incorrect attenuation on the spectrum analyzer can severely affect the IMD_3 measurement. Refer to the spectrum analyzer documentation for more information.

6. Measure and record the value of the following:
   - Amplitude of Carrier Tone 1
   - Amplitude of Carrier tone 2
   - Amplitude of 3rd order harmonic product 1, $2f_2–f_1$
   - Amplitude of 3rd order harmonic product 2, $2f_1–f_2$
7. Use the equation in Table 36 to calculate the IMD_3, and compare it to the test limit in Table 36.
8. Configure the NI 5451 according to the next configuration in Table 36 for the specific gain.
9. Repeat steps 2 through 8 for all gains in Table 36.
10. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14. If necessary, insert a 7 dB attenuator inline. Refer to the note in Table 36 for more information.
11. Repeat steps 2 through 9 for CH 1.

Table 36. Differential Main Path Intermodulation Distortion (IMD_3) Verification

Config.	CH	Gain	Tone 1 Frequency (MHz)	Tone 2 Frequency (MHz)	Center Frequency (MHz)	Spectrum Analyzer Attenuation (dB)	Spectrum Analyzer Reference Level (dBm)	IMD_3 (dBc)	Test Limit (dBc), typical
1	0, 1	0.1	9.9	10.1	10	0	–20		–89
2			19.9	20.1	20	0	–20		–83
3			39.9	40.1	40	0	–20		–78
4			59.9	60.1	60	0	–20	$Max(P_{\langle 2\times f_2 - f_1\rangle}, P_{\langle 2\times f_1 - f_2\rangle}) - Min(P_{f_1}, P_{f_2})$	–73
5			79.9	80.1	80	0	–20		–69
6			119.9	120.1	120	0	–20		–66
7			159.9	160.1	160	0	–20		–65
1	0, 1	0.5	9.9	10.1	10	25	0		–87
2			19.9	20.1	20	25	0		–85
3			39.9	40.1	40	25	0		–82
4			59.9	60.1	60	25	0	$Max(P_{\langle 2\times f_2 - f_1\rangle}, P_{\langle 2\times f_1 - f_2\rangle}) - Min(P_{f_1}, P_{f_2})$	–79
5			79.9	80.1	80	25	0		–75
6			119.9	120.1	120	25	0		–79
7			159.9	160.1	160	25	0		–75

Table 36. Differential Main Path Intermodulation Distortion (IMD_3) Verification (Continued)

Config.	CH	Gain	Tone 1 Frequency (MHz)	Tone 2 Frequency (MHz)	Center Frequency (MHz)	Spectrum Analyzer Attenuation (dB)	Spectrum Analyzer Reference Level (dBm)	IMD_3 (dBc)	Test Limit (dBc), typical
1	0, 1	1.25	9.9	10.1	10	35	10	$Max(P_{\langle 2\times f_2-f_1\rangle},P_{\langle 2\times f_1-f_2\rangle})-Min(P_{f_1},P_{f_2})$	–92
2			19.9	20.1	20	35	10		–87
3			39.9	40.1	40	35	10		–79
4			59.9	60.1	60	35	10		–72
5			79.9	80.1	80	35	10		–66
6			119.9	120.1	120	35	10		–61
7			159.9	160.1	160	35	10		–57
1	0, 1	2.5	9.9	10.1	10	35	15	$Max(P_{\langle 2\times f_2-f_1\rangle},P_{\langle 2\times f_1-f_2\rangle})-Min(P_{f_1},P_{f_2})$	–87
2			19.9	20.1	20	35	15		–82
3			39.9	40.1	40	35	15		–71
4			59.9	60.1	60	35	15		–63
5			79.9	80.1	80	35	15		–57
6			119.9	120.1	120	35	15		–51
7			159.9	160.1	160	30	15		–48
Note: You must add a 7 dB external attenuator for the 10 MHz and 20 MHz center frequency measurements for the 1.25 and 2.5 gains.									

Differential Direct Path

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 13.
2. Configure the spectrum analyzer according to Table 37 and the following characteristics:
   - Reference level: –6 dBm
   - RF attenuation: 20 dB
   - Detector mode: Max peak
   - Span: 700 kHz
   - Resolution bandwidth: 5 kHz
   - Video bandwidth: 20 kHz
   - Average: On
   - Sweep: 50
3. Configure the NI 5451 according to Table 37, and generate a waveform with the following characteristics:
   - Waveform data amplitude (each tone): –7 dBFS
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω (100 Ω differential)
   - Terminal configuration: Differential
4. Enable the TOI function.
5. To further try to optimize the measurement, go to the AMPT menu and change the RF ATTENUATION to minimize the spectrum analyzer distortion on the IMD_3 (TOI) reading.

Note Incorrect attenuation on the spectrum analyzer can severely affect the IMD_3 measurement. Refer to the spectrum analyzer documentation for more information.

6. Measure and record the value of the following:
   - Amplitude of Carrier Tone 1
   - Amplitude of Carrier tone 2
   - Amplitude of 3rd order harmonic product 1, $2f_2–f_1$
   - Amplitude of 3rd order harmonic product 2, $2f_1–f_2$
7. Use the equation in Table 37 to calculate the IMD_3 and compare it to the test limit in Table 37.
8. Configure the NI 5451 according to the next configuration in Table 37.
9. Repeat steps 2 through 8 for all configurations in Table 37.
10. Connect the differential CH 1 on the NI 5451 through the BALUN to the spectrum analyzer, as shown in Figure 14.
11. Repeat steps 2 through 9 for CH 1.

Table 37. Differential Direct Path Intermodulation Distortion (IMD_3) Verification

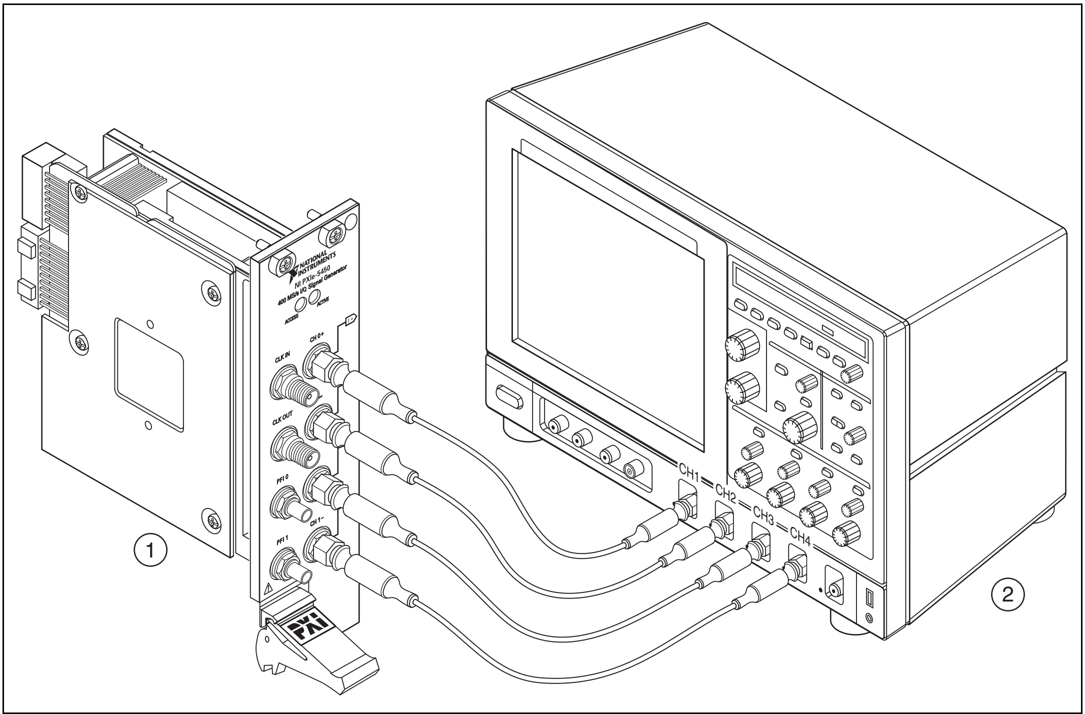
Config.	CH	Tone 1 Frequency (MHz)	Tone 2 Frequency (MHz)	Center Frequency (MHz)	IMD_3 (dBc)	Test Limit (dBc), typical
1	0, 1	9.9	10.1	10		≤–84
2		19.9	20.1	20		≤–81
3		39.9	40.1	40		≤–75
4		59.9	60.1	60	$Max(P_{\langle 2\times f_2 - f_1\rangle}, P_{\langle 2\times f_1 - f_2\rangle}) - Min(P_{f_1}, P_{f_2})$	≤–71
5		79.9	80.1	80		≤–68
6		119.9	120.1	120		≤–68
7		159.9	160.1	160		≤–66

Verifying Rise and Fall Time

Complete the following steps to verify the rise time and fall time of an NI 5451 module using an oscilloscope.

Main Path (Filter Disabled)

1. Connect the NI 5451 to the oscilloscope as shown in Figure 15.



1 NI 5451	2 Tektronix DPO70404 Oscilloscope

Figure 15. NI 5451 Connection to the Oscilloscope (CH 0 and CH 1)

Note Keep the cables as short as possible for all connections.

2. Configure the NI 5451, and generate a waveform with the following characteristics:
   - Channel: CH 0 and CH 1
   - Waveform: Square wave
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Frequency: 33 MHz
   - Gain: 2.5
   - Sample rate: 400 MS/s
   - Analog path: Main path
   - Load impedance: 50 Ω
   - Flatness correction: Disabled
   - Analog filter: Disabled
   - Terminal configuration: Differential
3. Initialize the oscilloscope.
   a. Press the DEFAULT SETUP to reset the oscilloscope to a known state.
   b. Enable oscilloscope channels 1 through 4.
   c. Press AUTOSET to acquire the waveform
4. Configure the oscilloscope with the following characteristics:
   - CH 1 to CH 4 amplitude: 350 mV/div
   - CH 1 to CH 4 termination: 50 Ω
   - Acquisition Mode: Average
   - Acquisition # of Wfms: 64
   - Horizontal Scale: 4 ns/div

   Four complete waveform periods, one for each channel, should be centered on the display.
5. Configure the oscilloscope measurements.
   - CH1 Time function: Rise Time (10% to 90%)
   - CH1 Time function: Fall Time (10% to 90%)
6. Wait for the measurement counter to reach at least 50 before making the reading.
7. Read and record the CH1 RISE mean as the rise time measurement.
8. Compare the rise time measurement to the test limit in Table 38.
9. Read and record the CH1 FALL mean as the fall time measurement.
10. Compare the fall time measurement to the test limit in Table 38.
11. Repeat steps 5 through 10, configuring the measurements for channels 2, 3, and 4.

Table 38. Main Path Filter Disabled Rise and Fall Time Verification

Config.	CH	Specification	Test Limit (ns), typical
1	0+, 0–, 1+, 1–	Rise time (10% to 90%)	≤1.5
2	0+, 0–, 1+, 1–	Fall time (10% to 90%)	≤1.5

Main Path (Filter Enabled)

1. Connect the NI 5451 to the oscilloscope as shown in Figure 15.
2. Configure the NI 5451, and generate a waveform with the following characteristics:
   - Channel: CH 0 and CH 1
   - Waveform: Square wave
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Frequency: 33 MHz
   - Gain: 2.5, Differential
   - Sample rate: 400 MS/s
   - Analog path: Main path
   - Load impedance: 50 Ω
   - Flatness correction: Disabled
   - Analog filter: Enabled
   - Terminal configuration: Differential
3. Initialize the oscilloscope.
   a. Press the DEFAULT SETUP to reset the oscilloscope to a known state.
   b. Enable oscilloscope channels 1 through 4.
   c. Press AUTOSET to acquire the waveform
4. Configure the oscilloscope with the following characteristics:
   - CH 1 to CH 4 amplitude: 350 mV/div
   - CH 1 to CH 4 termination: 50 Ω
   - Acquisition Mode: Average
   - Acquisition # of Wfms: 64
   - Horizontal Scale: 4 ns/div

   Four complete waveform periods, one for each channel, should be centered on the display.
5. Configure the oscilloscope measurements.
   - CH1 Time function: Rise Time (10% to 90%)
   - CH1 Time function: Fall Time (10% to 90%)
6. Wait for the measurement counter to reach at least 50 before making the reading.
7. Read and record the CH1 RISE mean as the rise time measurement.
8. Compare the rise time measurement to the test limit in Table 39.
9. Read and record the CH1 FALL mean as the fall time measurement.
10. Compare the fall time measurement to the test limit in Table 39.
11. Repeat steps 5 through 10, configuring the measurements for channels 2, 3, and 4.

Table 39. Main Path Filter Enabled Rise and Fall Time Verification

Config.	CH	Specification	Test Limit (ns), typical
1	0+, 0–, 1+, 1–	Rise time (10% to 90%)	≤3
2	0+, 0–, 1+, 1–	Fall time (10% to 90%)	≤3

Differential Direct Path

1. Connect the NI 5451 to the oscilloscope as shown in Figure 15.
2. Configure the NI 5451, and generate a waveform with the following characteristics:
   - Channel: CH 0 and CH 1
   - Waveform: Square wave
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Frequency: 33 MHz
   - Gain: 0.5
   - Sample rate: 400 MS/s
   - Analog path: Direct path
   - Load impedance: 50 Ω
   - Flatness correction: Disabled
   - Terminal configuration: Differential
3. Initialize the oscilloscope.
   a. Press the DEFAULT SETUP to reset the oscilloscope to a known state.
   b. Enable oscilloscope channels 1 through 4.
   c. Press AUTOSET to acquire the waveform
4. Configure the oscilloscope with the following characteristics:
   - CH 1 to CH 4 amplitude: 70 mV/div
   - CH 1 to CH 4 termination: 50 Ω
   - Acquisition Mode: Average
   - Acquisition # of Wfms: 64
   - Horizontal Scale: 4 ns/div

   Four complete waveform periods, one for each channel, should be centered on the display.
5. Configure the oscilloscope measurements.
   - CH1 Time function: Rise Time (10% to 90%)
   - CH1 Time function: Fall Time (10% to 90%)
6. Wait for the measurement counter to reach at least 50 before making the reading.
7. Read and record the CH1 RISE mean as the rise time measurement.
8. Compare the rise time measurement to the test limit in Table 40.
9. Read and record the CH1 FALL mean as the fall time measurement.
10. Compare the fall time measurement to the test limit in Table 40.
11. Repeat steps 5 through 10, configuring the measurements for channels 2, 3, and 4.

Table 40. Differential Direct Path Rise and Fall Time Verification

Config.	CH	Specification	Test Limit (ns), typical
1	0+, 0–, 1+, 1–	Rise time (10% to 90%)	≤3
2	0+, 0–, 1+, 1–	Fall time (10% to 90%)	≤3

Verifying Aberrations

Complete the following steps to verify the aberrations of an NI 5451 module using an oscilloscope.

1. Connect the NI 5451 to the oscilloscope as shown in Figure 15.
2. Configure the NI 5451 according to Table 41, and generate a waveform with the following characteristics:
   - Channel: CH 0 and CH 1
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Frequency: 10 MHz
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω
   - Flatness correction: Disabled
   - Terminal configuration: Differential

   Note If you're using the Direct path, you can limit the slew rate to 133 V/μs by creating a trapezoidal waveform with enough edge points at specific amplitudes to achieve the required rate of voltage change during the transitions. Create a linear array with 40 points: –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –1, –0.33, +0.33, +1, +1, +1, +1, +1, +1,+1, +1, +1, +1, +1, +1, +1, +1, +1, +1, +1, +1, +0.33, –0.33. This array totals 40 points with a 2.5 ns interval between them to generate a 10 MHz waveform frequency (0.1 μs period). Repeat this waveform ten times to have enough points to meet the minimum waveform size by concatenating the one period array within the loop ten times.

3. Initialize the oscilloscope.
   a. Press the DEFAULT SETUP to reset the oscilloscope to the original manufacturing state.
   b. Enable oscilloscope channels 1 through 4.
   c. Press AUTOSET to acquire the waveform
4. Configure the oscilloscope according to Table 41 and the following characteristics:
   - CH 1 to CH 4 termination: 50 Ω
   - Acquisition Mode: Average
   - Acquisition # of Wfms: 64
   - Horizontal Scale: 10 ns/div

   One complete waveform period should be displayed for each output terminal.
5. Configure the oscilloscope measurements.
   - CH 1 Amplitude: Positive Overshoot
   - CH 1 Amplitude: Negative Overshoot
6. Wait for the measurement counter to reach at least 64 before making the reading.
7. Read and record the channel 1 positive overshoot mean as the rising edge aberration measurement.
8. Compare the rising edge aberration measurement to the test limit in Table 41.
9. Read and record the channel 1 negative overshoot mean as the falling edge aberration measurement.
10. Compare the falling edge aberration measurement to the test limit in Table 41.
11. Repeat steps 5 through 10, configuring the measurements for channels 2, 3, and 4.
12. Repeat steps 2 through 11 for each configuration in Table 41.

Table 41. Aberration Time Verification

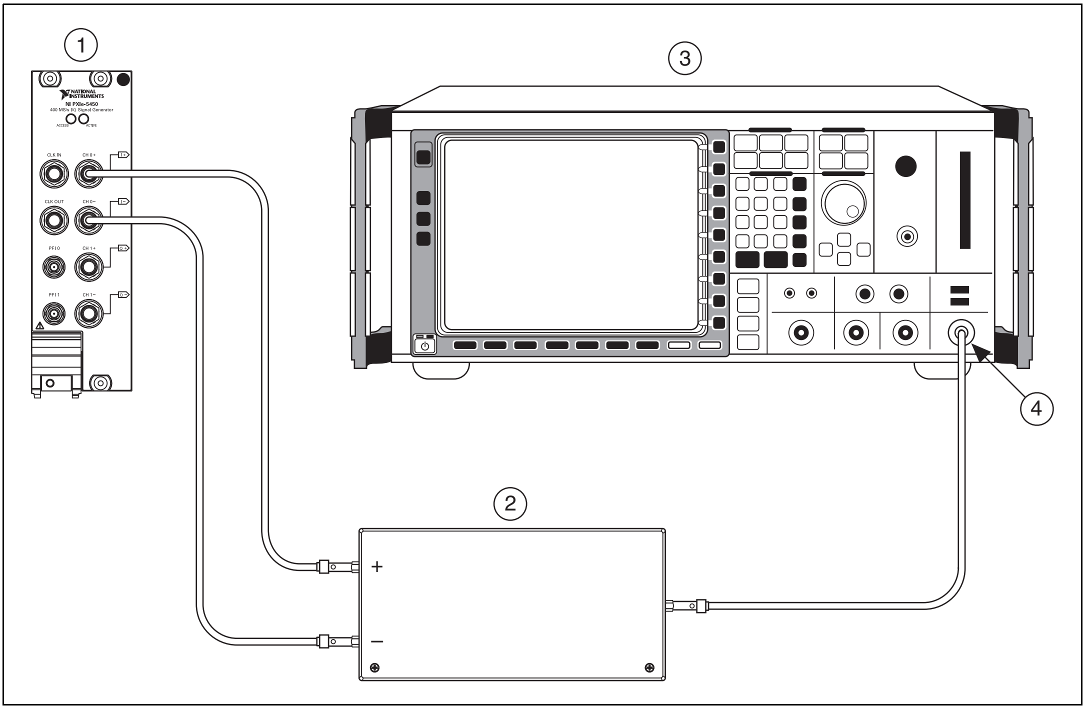
Config.	Analog Path	CH	Waveform	Analog Filter	Slew Rate Limit (V/us)	Gain	Scope Amplitude (mV/div)	Specification	Test Limit (%), typical
1	Main	0+, 0–, 1+, 1–	Square	Disabled	—	2.5	350	Rising edge aberration	≤3
2	Main	0+, 0–, 1+, 1–	Square	Disabled	—	2.5	350	Falling edge aberration	≤3
3	Main	0+, 0–, 1+, 1–	Square	Enabled	—	2.5	350	Rising edge aberration	≤18
4	Main	0+, 0–, 1+, 1–	Square	Enabled	—	2.5	350	Falling edge aberration	≤18
5	Direct	0+, 0–, 1+, 1–	Trapezoidal	Enabled	133	0.5	70	Rising edge aberration	≤7
6	Direct	0+, 0–, 1+, 1–	Trapezoidal	Enabled	133	0.5	70	Falling edge aberration	≤7

Verifying Phase Noise Density and Jitter

Complete the following steps to verify the phase noise density and jitter of an NI 5451 using a phase noise analyzer and BALUN.

Note (Main path only) You can verify phase noise without a BALUN using an FSUP and single-ended Main path as shown in Figure 11.

1. Connect the differential CH 0 on the NI 5451 through the BALUN to the phase noise analyzer, as shown in Figure 16.



1	NI 5451	3	R&S FSUP Phase Noise Analyzer
2	Picosecond 5320B BALUN	4	RF IN Connector

Figure 16. NI 5451 Connection to Phase Noise Analyzer using a BALUN (CH 0)

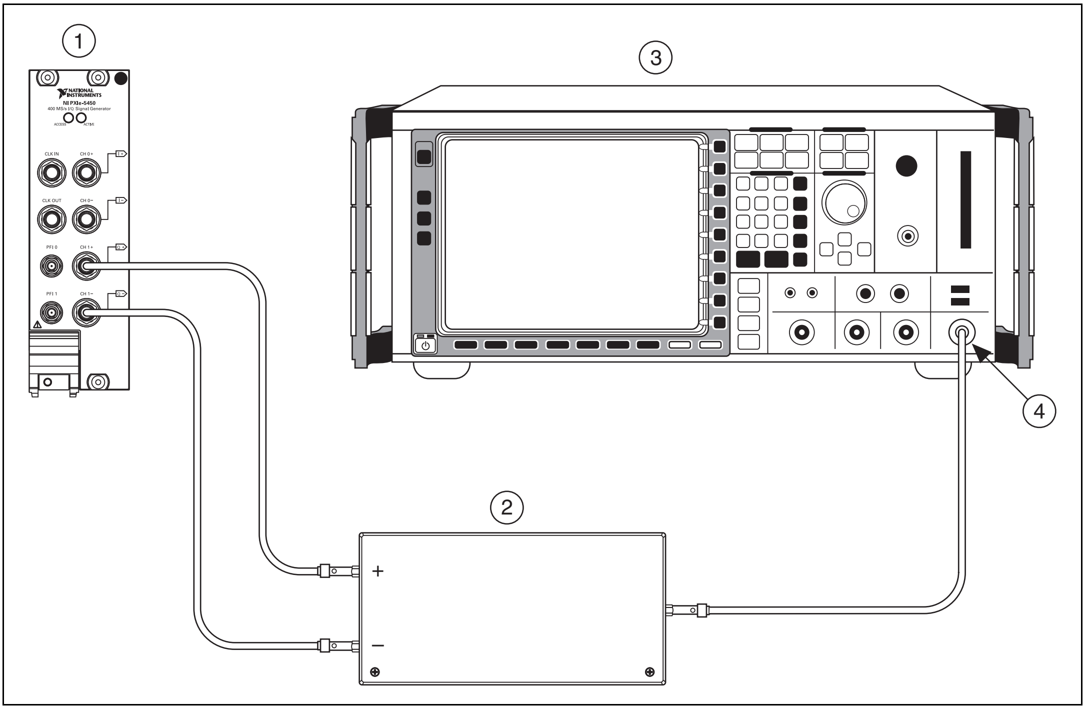
Note Use high quality 50 Ω SMA cables of the same electrical length. Keep the cables as short as possible for all connections.

2. Set the phase noise analyzer to its default, and configure it according to Table 42 and the following characteristics:
   - Measurement mode: Phase noise
   - Center frequency: 10 MHz
   - Level: 0 dBm
   - Sweep mode: Normal
   - Frequency span: 100 Hz to 1 MHz

Table 42. Offset Frequency Field Settings for Spot Noise

Offset Freq Field	Set to Frequency
Offset Freq1	100 Hz
Offset Freq2	1 kHz
Offset Freq3	10 kHz
Offset Freq4	100 kHz
Offset Freq5	1 MHz

3. Configure the NI 5451 according to Table 43, and generate a waveform with the following characteristics:
   - Waveform: Sine
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Sample rate: 400 MS/s
   - Load impedance: 50 Ω
   - Flatness correction: Disabled
   - Terminal configuration: Differential
4. Verify phase noise measurements.
   a. Configure the NI 5451 according to configuration 1 in Table 43 and enable output.
   b. Take a new phase noise measurement.
   c. Record the 10 MHz output "Spot Noise" readings.
   d. Compare the readings to the appropriate *Output Frequency* in Table 44.
5. Verify jitter measurements.
   a. Set the phase noise analyzer start frequency to 100 Hz.
   b. Set the phase noise analyzer span stop frequency to 100 kHz.
   c. Take a new phase noise measurement.
   d. Record the CH 0, 100 MHz RMS jitter reading.
   e. Compare the readings to the appropriate *Output Frequency* in Table 44.
6. Repeat steps 3 through 5 for all configurations in Table 43.
7. Connect the differential CH 1 on the NI 5451 through the BALUN to the phase noise analyzer, as shown in Figure 17.
8. Repeat steps 3 through 6 for all configurations in Table 43.



1	NI 5451	3	R&S FSUP Phase Noise Analyzer
2	Picosecond 5320B BALUN	4	RF IN Connector

Figure 17. NI 5451 Connection to a Phase Noise Analyzer Using a BALUN (CH 1)

Note Use high quality 50 Ω SMA cables of the same electrical length. Keep the cables as short as possible for all connections.

Table 43. Main Path Phase Noise Density Verification NI 5451 Configuration

Config.	CH	Analog Path	Gain	Output Frequency (MHz)	Reference Clock	Differential Load* (Ω)
1	0	Main	2.5	10	Internal	100
2	1	Main	2.5	100	Internal	100
3	0	Direct	0.5	10	Internal	100
4	1	Direct	0.5	100	Internal	100

* The NI-FGEN software load impedance is single ended. Therefore, setting the load impedance to 50 Ω in NI-FGEN is equal to 100 Ω differential.

Table 44. Phase Noise Density and Jitter Accuracy Verification

CH	Output Frequency (MHz)	Integrated Jitter* (fs)	Spot Noise (dBc/Hz)	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
0, 1	10	<350	Test limit, typical	<–121	<–137	<–146	<–152	<–153
	100	<350	Test limit, typical	<–101	<–119	<–126	<–136	<–141

* Jitter is integrated from 100 Hz to 100 kHz, using the internal reference clock.

Adjustment

An adjustment is required only once per year. Following the adjustment procedure automatically updates the calibration date and temperature in the EEPROM of the NI 5451.

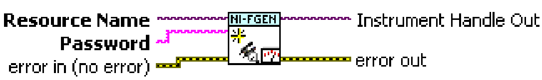
Adjustment corrects the following NI 5451 specifications:

- Main path DC ADC and reference adjustment
- Direct path DC ADC and reference adjustment
- Main path frequency response (flatness) adjustment
- Direct path frequency response (flatness) adjustment

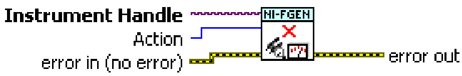
After adjustment, run self-calibration and then repeat the verification section to confirm that the adjustment was successful.

NI recommends that you always complete a full calibration to renew the calibration date and temperature. However, you can renew the calibration date and onboard calibration temperature without making any adjustments by completing the following steps.

1. Open an NI-FGEN external calibration session by calling the niFgen Init Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitExtCal` using the following parameters: **resourceName**: The name of the device you want to calibrate. This name can be found under Devices and Interfaces in MAX. **password**: The password required to open an external calibration session. The default password is `NI`. **vi**: A pointer to an IVI session. The variable passed by reference through this parameter receives the value that identifies the external calibration session created by this function. This value acts as the session handle and is passed as the first parameter to all subsequent NI-FGEN functions.

2. Close the instrument driver session and save the calibration date and temperature by calling the niFgen Close Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CloseExtCal` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **action**: If the external adjustment procedure completed without any errors, use `NIFGEN_VAL_EXT_CAL_COMMIT`. This function stores any new calibration constants, updated calibration dates, and updated calibration temperatures in the onboard EEPROM. If any errors occurred during the external adjustment procedure, or if you want to abort the operation, use `NIFGEN_VAL_EXT_CAL_ABORT`. This function then discards the new calibration constants and does not change any of the calibration data stored in the onboard EEPROM.

Adjusting the Main Path DC ADC Reference

Complete the following steps to adjust the main path DC ADC reference using a digital multimeter (DMM).

Note Allow the NI 5451 and support equipment to warm up for a minimum of 30 minutes prior to performing an adjustment.

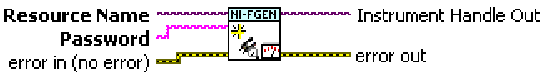
1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3. Only CH 0 is used in this adjustment.
2. Configure the DMM according to Configuration 1 in Table 45.

Table 45. Calibration Equipment Configuration for DC Amplitude Accuracy Adjustment

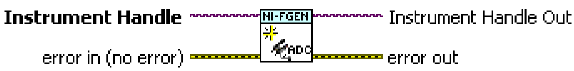
Configuration	Function	Range* (V)	Resolution*	Average Readings
1	DC Voltage	0.1	7.5 digits	10
2	DC Voltage	10	7.5 digits	10

*Assumes an NI 4071 DMM. For other DMMs, use the range closest to the values listed in this table. The input impedance should be equal to or greater than the values indicated in Table 1

3. Open an NI-FGEN external calibration session by calling the niFgen Init Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitExtCal` using the following parameters: **resourceName**: The name of the device you want to calibrate. This name can be found under Devices and Interfaces in MAX. **password**: The password required to open an external calibration session. The default password is `NI`. **vi**: A pointer to an IVI session. The variable passed by reference through this parameter receives the value that identifies the external calibration session created by this function. This value acts as the session handle and is passed as the first parameter to all subsequent NI-FGEN functions.

4. Call the niFgen Initialize Cal ADC Calibration VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitializeCalADC Calibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

5. Set the active channel by calling the niFgen Property Node and selecting **Active Channel**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_` **value**: `0`

6. Set the analog path by calling the niFgen Property Node and selecting **Output»Analog Path**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ANALOG_PATH` **value**: `NIFGEN_VAL_MAIN_ANALOG_PATH`

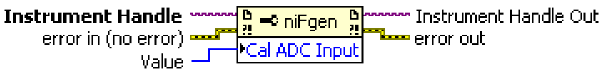
7. Set the active channel by calling the niFgen Property Node and selecting **Arbitrary Waveform» Gain**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ARB_GAIN` **value**: `1`

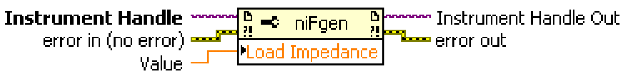
8. Set the gain DAC value by calling the niFgen Property Node and selecting **Instrument» Calibration»Gain DAC Value**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_GAIN_DAC_VALUE` **value**: `44000`

9. Set the calibration ADC input by calling the niFgen Property Node and selecting **Instrument»Calibration»Cal ADC Input**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_CAL_ADC_INPUT` **value**: `NIFGEN_VAL_ANALOG_OUTPUT_PLUS`

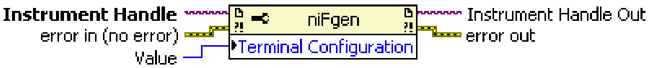
10. Set the output impedance by calling the niFgen Property Node and selecting **Output»Load Impedance**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_LOAD_IMPEDANCE` **value**: `1` GΩ

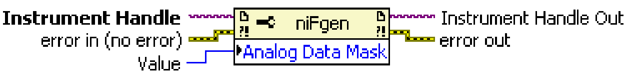
11. Set the offset value by calling the niFgen Property Node and selecting **Arbitrary Waveform»Offset**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ARB_OFFSET` **value**: `0`

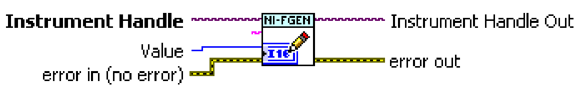
12. Set the terminal configuration value by calling the niFgen Property Node and selecting **Output»Terminal Configuration**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_TERMINAL_CONFIGURATION` **value**: `NIFGEN_VAL_DIFFERENTIAL`

13. Set the analog data mask value by calling the niFgen Property Node and selecting **Output»Data Mask»Analog Data Mask**.

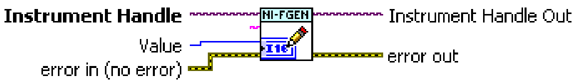
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ANALOG_DATA_MASK` **value**: `0`

14. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

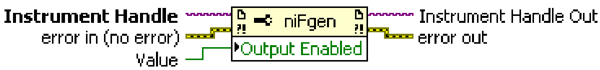
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_WriteBinary16AnalogStaticValue` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **value**: `0`

15. Wait 1,000 ms for the output to settle.

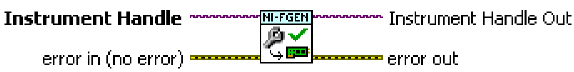
16. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_WriteBinary16 AnalogStaticValue` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **value**: `3277`

17. Disable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

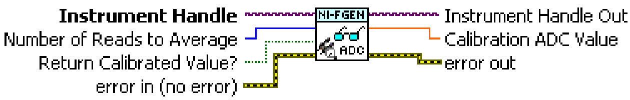
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ ENABLED` **value**: `VI_FALSE`

18. Commit the attribute values to the device by calling the niFgen Commit VI.

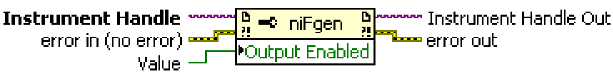
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

Note Do not insert any additional settling time between steps 18 and 19.

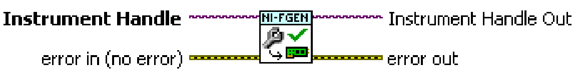
19. Measure the analog output voltage with the onboard calibration ADC by calling the niFgen Read CAL ADC VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ReadCalADC` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **numberOfReadsToAverage**: `5` **returnCalibratedValue**: `VI_FALSE` **calADCValue**: A ViReal64 variable. The variable passed by reference through this parameter receives the voltage measured by the onboard ADC. This value is cal ADC measurement 0, which is used in step 33.

20. Enable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

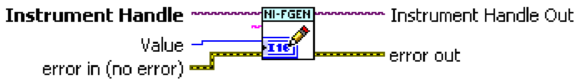
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_TRUE`

21. Commit the attribute values to the device by calling the niFgen Commit VI.

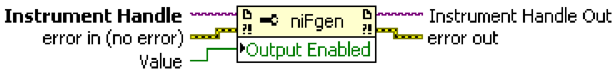
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

22. Wait 500 ms for the output to settle.
23. Use the DMM to measure the NI 5451 differential voltage output. This measurement, divided by 2, is external measurement 0, which is used in step 33.
24. Configure the DMM according to Configuration 2 in Table 45.

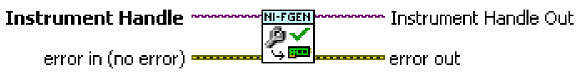
25. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_WriteBinary16 AnalogStaticValue` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **value**: `32767`

26. Disable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

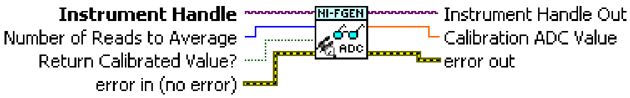
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_FALSE`

27. Commit the attribute values to the device by calling the niFgen Commit VI.

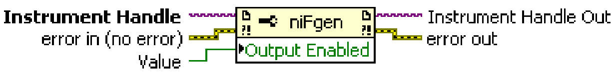
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Initialize FlatnessCalibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

Note Do not insert any additional settling time between steps 27 and 28.

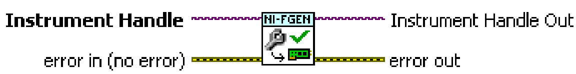
28. Measure the analog output voltage with the onboard calibration ADC by calling the niFgen Read CAL ADC VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ReadCalADC` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **numberOfReadsToAverage**: `5` **returnCalibratedValue**: `VI_FALSE` **calADCValue**: A ViReal64 variable. The variable passed by reference through this parameter receives the voltage measured by the onboard ADC. This value is cal ADC measurement 1, which is used in step 33.

29. Enable the analog output by calling the niFgen Property Node and selecting **Output» Output Enabled**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_TRUE`

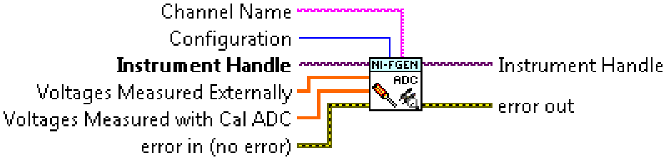
30. Commit the attribute values to the device by calling the niFgen Commit VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

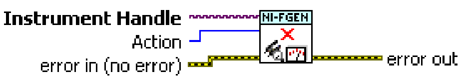
31. Wait 500 ms for the output to settle.

32. Use the DMM to measure the NI 5451 voltage output. This measurement, divided by 2, is external measurement 1, which is used in step 33.

33. Call the niFgen Cal Adjust Cal ADC VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CalAdjustCalADC` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **voltagesMeasured Externally**: An array containing two elements: The voltages, divided by 2 (external measurement 0, external measurement 1), that you measured with the DMM in the order they were measured. **voltagesMeasuredWith CalADC**: An array containing two elements: The single-ended voltages (cal ADC measurement 0, cal ADC measurement 1) measured with the onboard calibration ADC in the order they were measured.

34. Close the instrument driver session and save the calibration date and temperature by calling the niFgen Close Ext Cal VI.

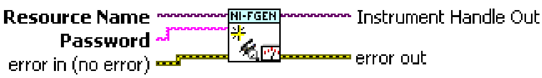
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CloseExtCal` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **action**: If the external adjustment procedure completed without any errors, use `NIFGEN_VAL_EXT_CAL_COMMIT`. This function stores any new calibration constants, updated calibration dates, and updated calibration temperatures in the onboard EEPROM. If any errors occurred during the external adjustment procedure, or if you want to abort the operation, use `NIFGEN_VAL_EXT_CAL_ABORT`. This function then discards the new calibration constants and does not change any of the calibration data stored in the onboard EEPROM.

Adjusting the Direct Path DC ADC Reference

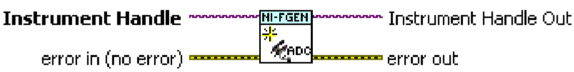
Complete the following steps to adjust the direct path DC ADC reference using a digital multimeter (DMM).

Note Allow the NI 5451 and support equipment to warm up for a minimum of 30 minutes prior to performing an adjustment.

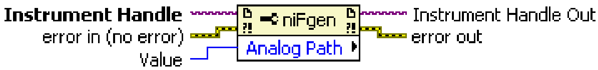
1. Connect the differential CH 0 on the NI 5451 to the DMM, as shown in Figure 3. Only CH 0 is used in this adjustment.
2. Configure the DMM according to Configuration 1 in Table 45.
3. Open an NI-FGEN external calibration session by calling the niFgen Init Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitExtCal` using the following parameters: **resourceName**: The name of the device you want to calibrate. This name can be found under Devices and Interfaces in MAX. **password**: The password required to open an external calibration session. The default password is `NI`. **vi**: A pointer to an IVI session. The variable passed by reference through this parameter receives the value that identifies the external calibration session created by this function. This value acts as the session handle and is passed as the first parameter to all subsequent NI-FGEN functions.

4. Call the niFgen Initialize Cal ADC Calibration VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitializeCalADC Calibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

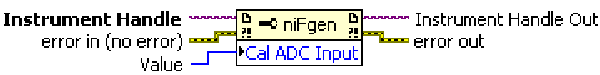
5. Set the analog path by calling the niFgen Property Node and selecting **Output»Analog Path**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ANALOG_PATH` **value**: `NIFGEN_VAL_DIRECT_ANALOG_PATH`

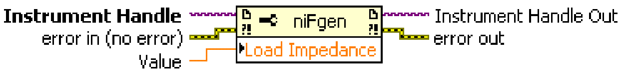
6. Set the gain DAC value by calling the niFgen Property Node and selecting **Instrument» Calibration»Gain DAC Value**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_GAIN_DAC_VALUE` **value**: `60948`

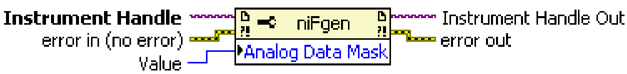
7. Set the calibration ADC input by calling the niFgen Property Node and selecting **Instrument» Calibration»Cal ADC Input**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_CAL_ADC_INPUT` **value**: `NIFGEN_VAL_ANALOG_OUTPUT_PLUS`

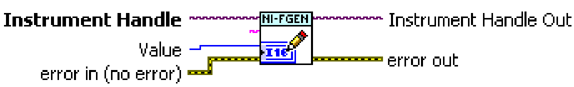
8. Set the output impedance by calling the niFgen Property Node and selecting **Output»Load Impedance**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_LOAD_IMPEDANCE` **value**: `1 GΩ`

9. Set the analog data mask value by calling the niFgen Property Node and selecting **Output»Data Mask»Analog Data Mask**.

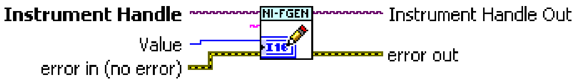
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ANALOG_DATA_MASK` **value**: `0`

10. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

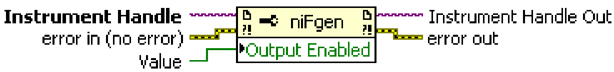
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_WriteBinary16 AnalogStaticValue` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **value**: `0`

11. Wait 1,000 ms for the output to settle.

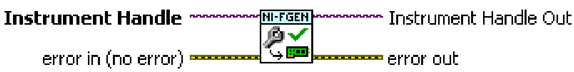
12. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_WriteBinary16 AnalogStaticValue` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **value**: `3113`

13. Disable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

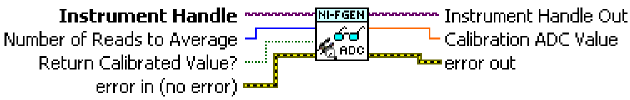
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_FALSE`

14. Commit the attribute values to the device by calling the niFgen Commit VI.

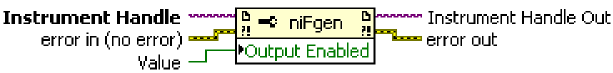
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

Note Do not insert any additional settling time between steps 14 and 15.

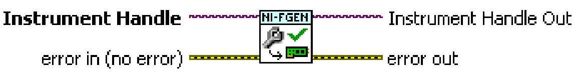
15. Measure the analog output voltage with the onboard calibration ADC by calling the niFgen Read CAL ADC VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ReadCalADC` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **numberOfReadsToAverage**: `5` **returnCalibratedValue**: `VI_FALSE` **calADCValue**: A ViReal64 variable. The variable passed by reference through this parameter receives the voltage measured by the onboard ADC. This value is cal ADC measurement 0, which is used in step 29.

16. Enable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

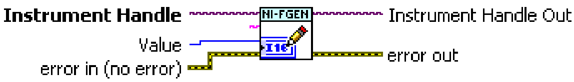
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_TRUE`

17. Commit the attribute values to the device by calling the niFgen Commit VI.

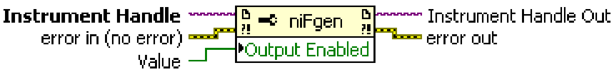
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

18. Wait 500 ms for the output to settle.
19. Use the DMM to measure the NI 5451 differential voltage output. This measurement, divided by 2, is external measurement 0, which is used in step 29.
20. Configure the DMM according to Configuration 2 in Table 45.

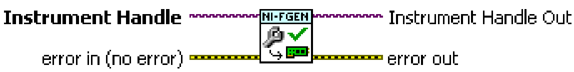
21. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_WriteBinary16 AnalogStaticValue` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **value**: `32767`

22. Disable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

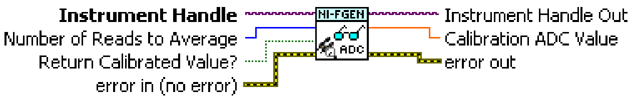
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_FALSE`

23. Commit the attribute values to the device by calling the niFgen Commit VI.

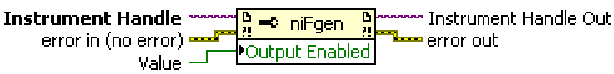
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Initialize FlatnessCalibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

Note Do not insert any additional settling time between steps 23 and 24.

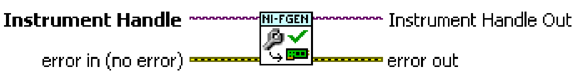
24. Measure the analog output voltage with the onboard calibration ADC by calling the niFgen Read CAL ADC VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ReadCalADC` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **numberOfReadsToAverage**: `5` **returnCalibratedValue**: `VI_FALSE` **calADCValue**: A ViReal64 variable. The variable passed by reference through this parameter receives the voltage measured by the onboard ADC. This value is cal ADC measurement 1, which is used in step 29.

25. Enable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

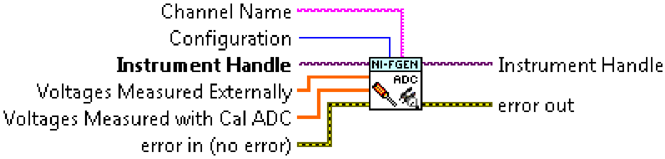
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_TRUE`

26. Commit the attribute values to the device by calling the niFgen Commit VI.

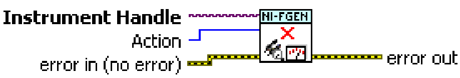
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

27. Wait 500 ms for the output to settle.
28. Use the DMM to measure the NI 5451 voltage output. This measurement, divided by 2, is external measurement 1, which is used in step 29.

29. Call the niFgen Cal Adjust Cal ADC VI.

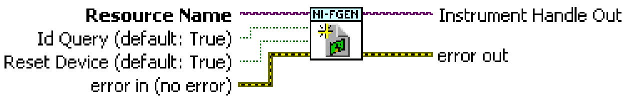
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CalAdjustCalADC` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **voltagesMeasured Externally**: An array containing two elements: The voltages, divided by 2 (external measurement 0, external measurement 1), that you measured with the DMM in the order they were measured. **voltagesMeasuredWith CalADC**: An array containing two elements: The single-ended voltages (cal ADC measurement 0, cal ADC measurement 1) measured with the onboard calibration ADC in the order they were measured.

30. Close the instrument driver session and save the calibration date and temperature by calling the niFgen Close Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CloseExtCal` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **action**: If the external adjustment procedure completed without any errors, use `NIFGEN_VAL_EXT_CAL_COMMIT`. This function stores any new calibration constants, updated calibration dates, and updated calibration temperatures in the onboard EEPROM. If any errors occurred during the external adjustment procedure, or if you want to abort the operation, use `NIFGEN_VAL_EXT_CAL_ABORT`. This function then discards the new calibration constants and does not change any of the calibration data stored in the onboard EEPROM.

Performing Self-Calibration

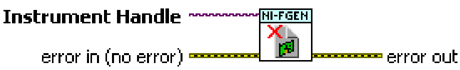
1. Open a session by calling the niFgen Initialize VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_init` using the following parameters: **vi**: The session handle returned from `niFgen_init`.

2. Update gain self-calibration on the onboard EEPROM to use the new DC ADC constants by calling the niFgen Self Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SelfCal` using the following parameters: **vi**: The session handle returned from `niFgen_Init`

3. End the session by calling the niFgen Close VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_close` using the following parameter: **vi**: The session handle returned from `niFgen_init`

You have finished adjusting the main and direct path DC ADC reference of the NI 5451 and self-calibration. Repeat the *Verification* section to reverify the performance of the NI 5451 after all adjustments have been completed.

Adjusting the Main Path Frequency Response (Flatness)

Complete the following steps to adjust the main path frequency response (flatness) using a power meter(s) and 7 dB attenuators.

Note Allow the NI 5451 and support equipment to warm up for a minimum of 30 minutes prior to performing an adjustment.

1. Connect the power meters to the CH 0 output terminals of the NI 5451 as shown in Figure 9.

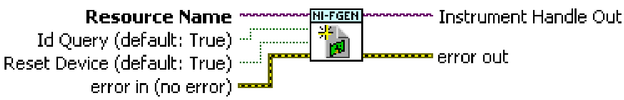
Note If you are using a single power meter, load the unused terminal with the 7 dB attenuator and the 50 Ω termination.

2. Configure the power meter as follows:
   - Multichannel
   - Average: 128
   - Measure watts
   - Channel 1 power sensor connected to the NI 5451(+)

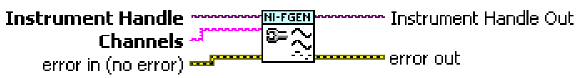
- Channel 2 power sensor connected to the NI 5451(–)
- High accuracy

Note If you have not already done so, disable the NI 5451 outputs, and then null the power meter(s) according to the power meter documentation. Allow 10 seconds for the power meter to stabilize before recording each reading.

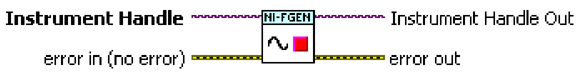
3. Open a session by calling the niFgen Initialize VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_init` using the following parameters: **vi**: The session handle returned from `niFgen_init`.

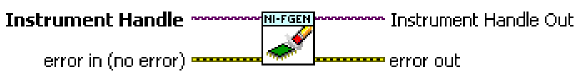
4. Prepare the channel for waveform generation by calling the niFgen Configure Channels VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ConfigureChannels` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal`. **Channels**: `"0"` when calibrating CH 0. `"1"` when calibrating CH 1.

5. Abort waveform generation by calling the niFgen Abort Generation VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_AbortGeneration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

6. Clear the NI-FGEN memory by calling the niFgen Clear Arbitrary Memory VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ClearArbMemory` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal`

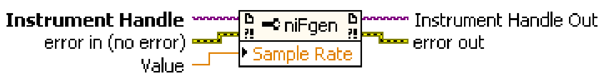
7. Set the analog path by calling the niFgen Property Node and selecting **Output»Analog Path**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ANALOG_PATH` **value**: `NIFGEN_VAL_MAIN_ANALOG_ PATH`

8. Set the scaling factor by calling the niFgen Property Node and selecting **Arbitrary Waveform» Gain**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **attributeId**: `NIFGEN_ATTR_ARB_GAIN` **value**: Refer to Table 47 for the current iteration.

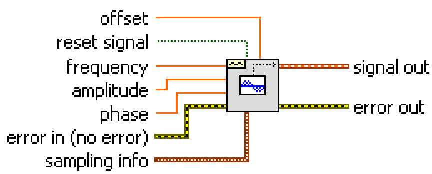
9. Set the sample rate by calling the niFgen Property Node and selecting **Clocks»Sample Clock» Rate**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttributeViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **attributeId**: `NIFGEN_ATTR_ARB_ SAMPLE_RATE` **value**: `400,000,000`

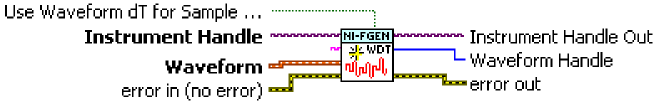
10. Set the flatness correction factor by calling the niFgen Property Node and selecting **Output» Filters»Flatness Correction Enabled**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttributeViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **attributeId**: `NIFGEN_ATTR_FLATNESS_ CORRECTION_ENABLED` **value**: `VI_FALSE`

11. If you use C function calls, generate a sine wave. If you use LabVIEW, configure a waveform by calling the LabVIEW Sine Waveform VI with the following inputs:

LabVIEW Block Diagram

• **frequency**: The *Frequency* value in Table 49 for the current iteration • **amplitude**: `1` • **phase**: `0` • **resetSignal**: `VI_TRUE` • **offset**: `0.0` • **samplingInfo**: A cluster of two elements: Sampling rate of 400,000,000 and the *Number of Samples* value in Table 46 for the current iteration.

12. Create an onboard waveform by calling the niFgen Create Waveform (WDT) instance of the niFgen Create Waveform (poly) VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CreateWaveformF64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **waveform**: The signal out returned from the Sine Waveform VI in step 11. **waveformSize**: Value from Table 46. **waveformDataArray**: Array of sine waveform data. **waveformHandle**: A pointer to a waveform. The variable passed by reference through this parameter acts as a handle to the waveform and can be used for setting the active waveform, changing the data in the waveform, building sequences of waveforms, or deleting the waveform when it is no longer needed.

13. Initiate waveform generation by calling the niFgen Initiate Generation VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitiateGeneration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

14. Record the readings from the power meters.
15. Repeat steps 5 through 14 for each frequency listed in Table 46.

Note If you are using a single power meter, load the unused terminal with the 7 dB attenuator and the 50 Ω termination.

16. Convert the power measurements from watts to volts by taking the square root.
17. Add the positive terminal voltage and the negative terminal voltage measurements for each frequency in Table 46 to obtain the differential voltage result.
18. Remove the DAC sinc response by dividing each differential voltage result by $\sin(x)/x$.

    where

$$x = \left(\frac{OutputFrequency \times \pi}{400,000,000}\right)$$

19. Make measurements relative to the 50 kHz result by dividing each differential voltage result by the differential voltage measured with a waveform frequency of 50 kHz.

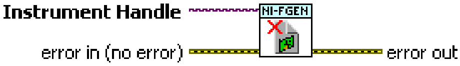
Table 46. Adjusting Sine Wave Flatness Correction Frequencies and Samples

Frequency	Samples
50 kHz, Reference	16,000
10 MHz	800,000
20 MHz	400,000
30 MHz	400,000
40 MHz	200,000
50 MHz	160,000
60 MHz	200,000
70 MHz	400,000
80 MHz	100,000
90 MHz	1,600,000
100 MHz	80,000
110 MHz	1,200,000
120 MHz	100,000
130 MHz	400,000
140 MHz	200,000
150 MHz	80,000
160 MHz	50,000
170 MHz	800,000
180 MHz	800,000
190 MHz	400,000

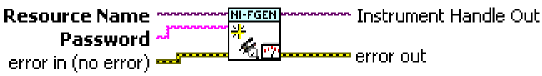
Table 47. Adjusting Sine Wave Flatness Gain Settings

Config.	CH	Gain
0	0, 1	2.5
1		0.8870
2		0.05597

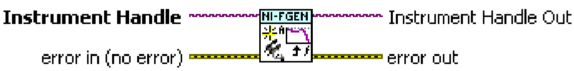
20. End the session by calling the niFgen Close VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_close` using the following parameter: **vi**: The session handle returned from `niFgen_init`

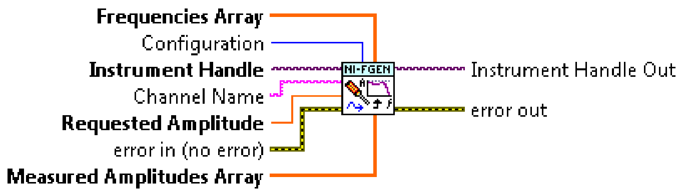
21. Repeat steps 3 through 20 for each configuration in Table 47.
22. Connect the power meters to the CH 1 output terminals of the NI 5451 as shown in Figure 10.
23. Repeat steps 3 through 21 for CH 1.
24. Open an NI-FGEN external calibration session by calling the niFgen Init Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitExtCal` using the following parameters: **resourceName**: The name of the device you want to calibrate. This name can be found under Devices and Interfaces in MAX. **password**: The password required to open an external calibration session. The default password is `NI`. **vi**: A pointer to an IVI session. The variable passed by reference through this parameter receives the value that identifies the external calibration session created by this function. This value acts as the session handle and is passed as the first parameter to all subsequent NI-FGEN functions.

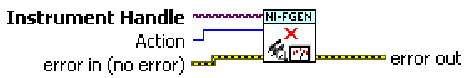
25. Initialize flatness calibration by calling the niFgen Initialize Flatness Calibration VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitializeFlatnessCalibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

26. Adjust the onboard calibration constants by calling the niFgen Cal Adjust Flatness VI for each configuration in Table 48.

LabVIEW Block Diagram	C/C++ Function Call
 	Call `niFgen_CalAdjust Flatness` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: Refer to Table 48. **requestedAmplitude**: `1` **configuration**: Refer to Table 48. **frequenciesArray**: An array of the frequencies from Table 46, including the 50 kHz Reference. **measuredAmplitudesArray**: Refer to Table 48.

27. Close the instrument driver session and save the calibration date and temperature by calling the niFgen Close Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
 	Call `niFgen_CloseExtCal` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **action**: If the external adjustment procedure completed without any errors, use `NIFGEN_VAL_EXT_CAL_COMMIT`. This function stores any new calibration constants, updated calibration dates, and updated calibration temperatures in the onboard EEPROM. If any errors occurred during the external adjustment procedure, or if you want to abort the operation, use `NIFGEN_VAL_EXT_CAL_ABORT`. This function then discards the new calibration constants and does not change any of the calibration data stored in the onboard EEPROM.

You have finished adjusting the main path frequency response (flatness) of the NI 5451. Repeat the *Verification* section to reverify the performance of the NI 5451 after adjustments.

Table 48. Flatness Calibration Configuration

Config.	NI-FGEN ChannelName	NI-FGEN Configuration	NI-FGEN measuredAmplitudesArray
0	`"0"`	NIFGEN_VAL_CAL_CONFIG_ MAIN_PATH_0 dB	Values calculated in step 19 for Config. 0, CH 0 in Table 47.
1	`"0"`	NIFGEN_VAL_CAL_CONFIG_ MAIN_PATH_–9 dB	Values calculated in step 19 for Config. 1, CH 0 in Table 47.
2	`"0"`	NIFGEN_VAL_CAL_CONFIG_ MAIN_PATH_–33 dB	Values calculated in step 19 for Config. 2, CH 0 in Table 47.
3	`"1"`	NIFGEN_VAL_CAL_CONFIG_ MAIN_PATH_0 dB	Values calculated in step 19 for Config. 0, CH 1 in Table 47.
4	`"1"`	NIFGEN_VAL_CAL_CONFIG_ MAIN_PATH_–9 dB	Values calculated in step 19 for Config. 1, CH 1 in Table 47.
5	`"1"`	NIFGEN_VAL_CAL_CONFIG_ MAIN_PATH_–33 dB	Values calculated in step 19 for Config. 2, CH 1in Table 47.

Adjusting the Direct Path Frequency Response (Flatness)

Complete the following steps to adjust the direct path frequency response (flatness) using a power meter(s) and 7 dB attenuators.

Note Allow the NI 5451 and support equipment to warm up for a minimum of 30 minutes prior to performing an adjustment.

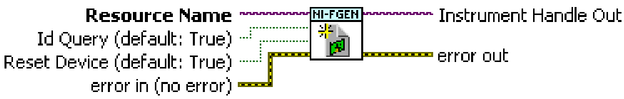
1. Connect the power meters to the CH 0 output terminals of the NI 5451 as shown in Figure 9.

Note If you are using a single power meter, load the unused terminal with the 7 dB attenuator and the 50 Ω termination.

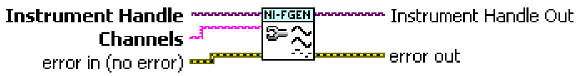
2. Configure the power meter as follows:
   - Multichannel
   - Average: 128
   - Measure watts
   - Channel 1 power sensor connected to the NI 5451(+)
   - Channel 2 power sensor connected to the NI 5451(–)
   - High accuracy

Note If you have not already done so, disable the NI 5451 outputs, and then null the power meter(s) according to the power meter documentation. Allow 10 seconds for the power meter to stabilize before recording each reading.

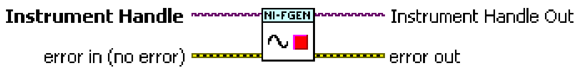
3. Open a session by calling the niFgen Initialize VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_init` using the following parameters: **vi**: The session handle returned from `niFgen_init`.

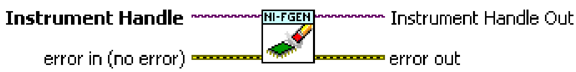
4. Prepare the channel for waveform generation by calling the niFgen Configure Channels VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ConfigureChannels` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal`. **Channels**: `"0"` when calibrating CH 0. `"1"` when calibrating CH 1.

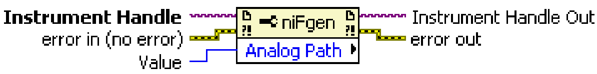
5. Abort waveform generation by calling the niFgen Abort Generation VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_AbortGeneration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

6. Clear the NI-FGEN memory by calling the niFgen Clear Arbitrary Memory VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_ClearArbMemory` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal`

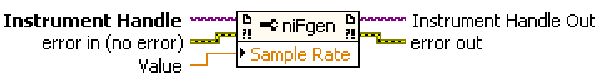
7. Set the analog path by calling the niFgen Property Node and selecting **Output»Analog Path**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViInt32` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeID**: `NIFGEN_ATTR_ANALOG_PATH` **value**: `NIFGEN_VAL_DIRECT_ANALOG_PATH`

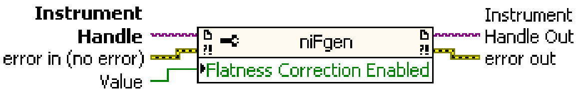
8. Set the scaling factor by calling the niFgen Property Node and selecting **Arbitrary Waveform» Gain**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **attributeId**: `NIFGEN_ATTR_ARB_GAIN` **value**: `0.5`

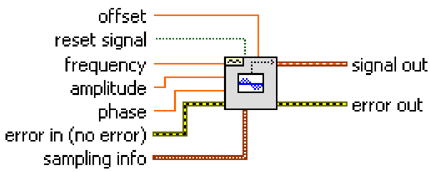
9. Set the sample rate by calling the niFgen Property Node and selecting **Clocks»Sample Clock» Rate**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttributeViReal64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **attributeId**: `NIFGEN_ATTR_ARB_SAMPLE_RATE` **value**: `400,000,000`

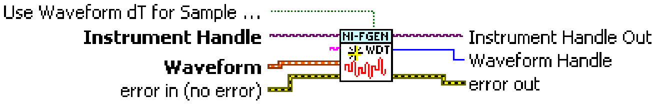
10. Set the flatness correction factor by calling the niFgen Property Node and selecting **Output»Filters»Flatness Correction Enabled**.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttributeViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **attributeId**: `NIFGEN_ATTR_FLATNESS_CORRECTION_ENABLED` **value**: `VI_FALSE`

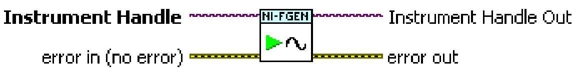
11. If you use C function calls, generate a sine wave. If you use LabVIEW, configure a waveform by calling the LabVIEW Sine Waveform VI with the following inputs:

LabVIEW Block Diagram
 • **frequency**: The *Frequency* value in Table 49 for the current iteration • **amplitude**: `1` • **phase**: `0` • **resetSignal**: `VI_TRUE` • **offset**: `0.0` • **samplingInfo**: A cluster of two elements: Sampling rate of 400,000,000 and the *Samples* value in Table 49 for the current iteration.

12. Create an onboard waveform by calling the niFgen Create Waveform (WDT) instance of the niFgen Create Waveform (poly) VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CreateWaveformF64` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **waveform**: The signal out returned from the Sine Waveform VI in step 11. **waveformSize**: Value from Table 49. **waveformDataArray**: Array of sine waveform data. **waveformHandle**: A pointer to a waveform. The variable passed by reference through this parameter acts as a handle to the waveform and can be used for setting the active waveform, changing the data in the waveform, building sequences of waveforms, or deleting the waveform when it is no longer needed.

13. Initiate waveform generation by calling the niFgen Initiate Generation VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitiateGeneration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

14. Record the readings from the power meters.
15. Repeat steps 5 through 14 for each frequency listed in Table 49.

Note If you are using a single power meter, load the unused terminal with the 7 dB attenuator and the 50 Ω termination.

16. Convert the power measurements from watts to volts by taking the square root.
17. Add the positive terminal voltage and the negative terminal voltage measurements for each frequency in Table 49 to obtain the differential voltage result.

18. Remove the DAC sinc response by dividing each differential voltage result by $\sin(x)/x$.

    where

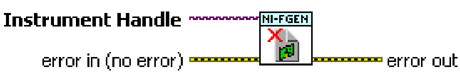
$$x = \left(\frac{OutputFrequency \times \pi}{400,000,000}\right)$$

19. Make measurements relative to the 50 kHz result by dividing each differential voltage result by the differential voltage measured with a waveform frequency of 50 kHz.

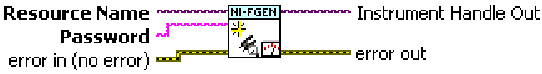
Table 49. Frequencies and Samples for Adjusting Sine Wave Flatness Correction

Frequency	Samples
50 kHz, Reference	16,000
10 MHz	800,000
20 MHz	400,000
30 MHz	400,000
40 MHz	200,000
50 MHz	160,000
60 MHz	200,000
70 MHz	400,000
80 MHz	100,000
90 MHz	1,600,000
100 MHz	80,000
110 MHz	1,200,000
120 MHz	100,000
130 MHz	400,000
140 MHz	200,000
150 MHz	80,000
160 MHz	50,000
170 MHz	800,000
180 MHz	800,000
190 MHz	400,000

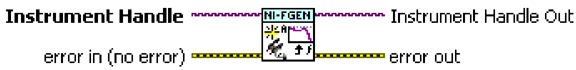
20. End the session by calling the niFgen Close VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_close` using the following parameter: **vi**: The session handle returned from `niFgen_init`

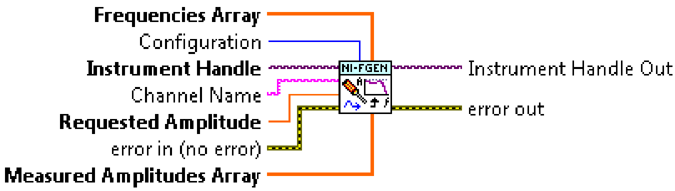
21. Connect the power meters to the CH 1 output terminals of the NI 5451 as shown in Figure 10.
22. Repeat steps 3 through 20 for CH 1.
23. Open an NI-FGEN external calibration session by calling the niFgen Init Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitExtCal` using the following parameters: **resourceName**: The name of the device you want to calibrate. This name can be found under Devices and Interfaces in MAX. **password**: The password required to open an external calibration session. The default password is `NI`. **vi**: A pointer to an IVI session. The variable passed by reference through this parameter receives the value that identifies the external calibration session created by this function. This value acts as the session handle and is passed as the first parameter to all subsequent NI-FGEN functions.

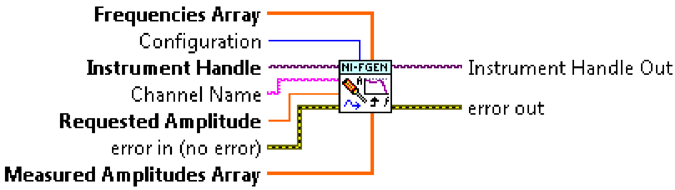
24. Initialize flatness calibration by calling the niFgen Initialize Flatness Calibration VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitializeFlatness Calibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

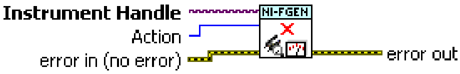
25. Adjust the onboard calibration constants by calling the niFgen Cal Adjust Flatness VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CalAdjustFlatness` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `"0"` **requestedAmplitude**: `1` **configuration**: `NIFGEN_VAL_CAL_CONFIG_DIRECT_PATH` **frequenciesArray**: An array of the frequencies from Table 49, including the 50 kHz Reference. **measuredAmplitudesArray**: An array of the amplitudes calculated in step 19 for CH 0.

26. Adjust the onboard calibration constants by calling the niFgen Cal Adjust Flatness VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CalAdjustFlatness` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `"1"` **requestedAmplitude**: `1` **configuration**: `NIFGEN_VAL_CAL_CONFIG_DIRECT_PATH` **frequenciesArray**: An array of the frequencies from Table 49, including the 50 kHz Reference. **measuredAmplitudesArray**: An array of the amplitudes calculated in step 19 for CH 1.

27. Close the instrument driver session and save the calibration date and temperature by calling the niFgen Close Ext Cal VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CloseExtCal` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **action**: If the external adjustment procedure completed without any errors, use `NIFGEN_VAL_EXT_CAL_COMMIT`. This function stores any new calibration constants, updated calibration dates, and updated calibration temperatures in the onboard EEPROM. If any errors occurred during the external adjustment procedure, or if you want to abort the operation, use `NIFGEN_VAL_EXT_CAL_ABORT`. This function then discards the new calibration constants and does not change any of the calibration data stored in the onboard EEPROM.

You have finished adjusting the direct path frequency response (flatness) of the NI 5451. Repeat the *Verification* section to reverify the performance of the NI 5451 after adjustments.

Where to Go for Support

The National Instruments Web site 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.

National Instruments corporate headquarters is located at 11500 North Mopac Expressway, Austin, Texas, 78759-3504. National Instruments also has offices located around the world to help address your support needs. For telephone support in the United States, create your service request at `ni.com/support` and follow the calling instructions or dial 512 795 8248. For telephone support outside the United States, 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.

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