CALIBRATION PROCEDURE

NI 5450

This document describes processes to calibrate the National Instruments PXIe-5450 (NI 5450) differential I/Q signal generator. This document provides performance tests to verify if the instrument is performing within the published specifications. For more information about calibration, visit `ni.com/calibration`.

Contents

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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 **File»Page Setup»Options** directs you to pull down the **File** menu, select the **Page Setup** item, and select **Options** from the last dialog box.

This icon denotes a 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 5450 requires installing NI-FGEN version 2.6 or later on the calibration system. You can download the NI-FGEN instrument driver from the Instrument Driver Network Web site at `ni.com/idnet`. 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 CD.

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

For information about NI-FGEN and the NI 5450, refer to the following documents:

- *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 5450 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 5450 specifications:

- *NI 5450 Specifications*—provides the published specification values for the NI 5450.

Note If you are using NI-FGEN 2.6, the *NI 5450 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

A calibration is required once a year; however, the measurement accuracy demands of your application determine how often external calibration should be performed.

Test Equipment

Table 1 lists the equipment required to calibrate the NI 5450. 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 5450

Calibration Procedure	Required Equipment	Recommended Instruments	Minimum Specifications
DC Amplitude Accuracy, DC Amplitude AC Amplitude Channel-to-Channel Relative Accuracy, Differential Offset, Common Mode Offset, AC Amplitude Accuracy, Channel-to-Channel Relative Accuracy, DC ADC and Reference Adjustment*	Digital multimeter (DMM)	NI PXI-4071	DCV accuracy: ≤ 0.05% DCV input impedance: ≥ 1 GΩ ACV accuracy: ≤ 0.13% ACV input impedance: ≥ 10 MΩ Bandwidth: ≥ 100 kHz

Table 1. Equipment Required for Calibrating the NI 5450 (Continued)

Calibration Procedure	Required Equipment	Recommended Instruments	Minimum Specifications
Channel-to-Channel Timing Alignment Accuracy, Rise/Fall Time[†], Aberrations[†]	Digital oscilloscope (DPO)	Tektronix DPO70404	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)
Frequency Response (Flatness) Accuracy, Channel-to-Channel Frequency Response (Flatness) Matching Accuracy, Frequency Response (Flatness) Adjustment[*]	Power meter/sensor (x2)[‡]	Rohde & Schwarz (R&S) NRP-Z91	VSWR: (50 kHz to 120 MHz) ≤ 1.11 Relative power accuracy: ≤ 0.022 dB
	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 (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 5450 (Continued)

Calibration Procedure	Required Equipment	Recommended Instruments	Minimum Specifications
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)†	Spectrum analyzer	R&S FSU26 #SN20 and above with improved phase noise • FSU-B23 20 dB preamplifier • FSU-B25 electronic attenuator	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
Output Phase Noise†, Output Jitter†	Phase noise analyzer	R&S FSUP	SSB phase noise (1 Hz) at the offset frequencies must be at least 3 dB better than the NI 5450 specification.

Table 1. Equipment Required for Calibrating the NI 5450 (Continued)

Calibration Procedure	Required Equipment	Recommended Instruments	Minimum Specifications
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†	BALUN	Picosecond 5320B	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 in/lb)
—	SMA 50 Ω high quality cables (x4)	—	1 ft. 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 5450 short. Long cables and wires act as antennae, picking up noise that can affect measurements.
- Keep the NI 5450 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 5450 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 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

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

Self-Calibration

The NI 5450 is capable of performing self-calibration, which adjusts the gain of the direct path and channel-to-channel timing alignment. An onboard, 24-bit ADC and precision voltage reference are used to calibrate the DC gain. 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 and time.

Note Common mode offset is minimized through active circuitry and is not adjusted in self-calibration. Differential offset is not adjusted during self-calibration.

Self-calibration can be initiated from MAX, 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*. Both sets of test limits include the *Measurement Uncertainty*. The After Adjustment test limits are more restrictive than the As Found test limits because they do not include errors that result from the long-term drift of the instrument. 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 5450 specifications. Refer to Table 1 for recommendations about choosing an instrument for each test.

Required verification tests the following NI 5450 specifications:

- DC amplitude absolute accuracy
- Differential offset
- Common mode offset
- DC amplitude channel-to-channel relative accuracy
- AC amplitude absolute accuracy
- AC 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 5450 specifications:

- Channel-to-channel frequency response (flatness) matching accuracy
- Analog bandwidth
- Spurious free dynamic range (SFDR) with harmonics
- Spurious free dynamic range without harmonics
- Total harmonic distortion (THD)
- Intermodulation distortion (IMD_3)
- Output phase noise
- Output jitter

- Rise/fall time
- Aberrations

Verification of the NI 5450 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-5450 front panel connectors. You can find information about the functions of these connectors in the *NI Signal Generators Getting Started Guide*.

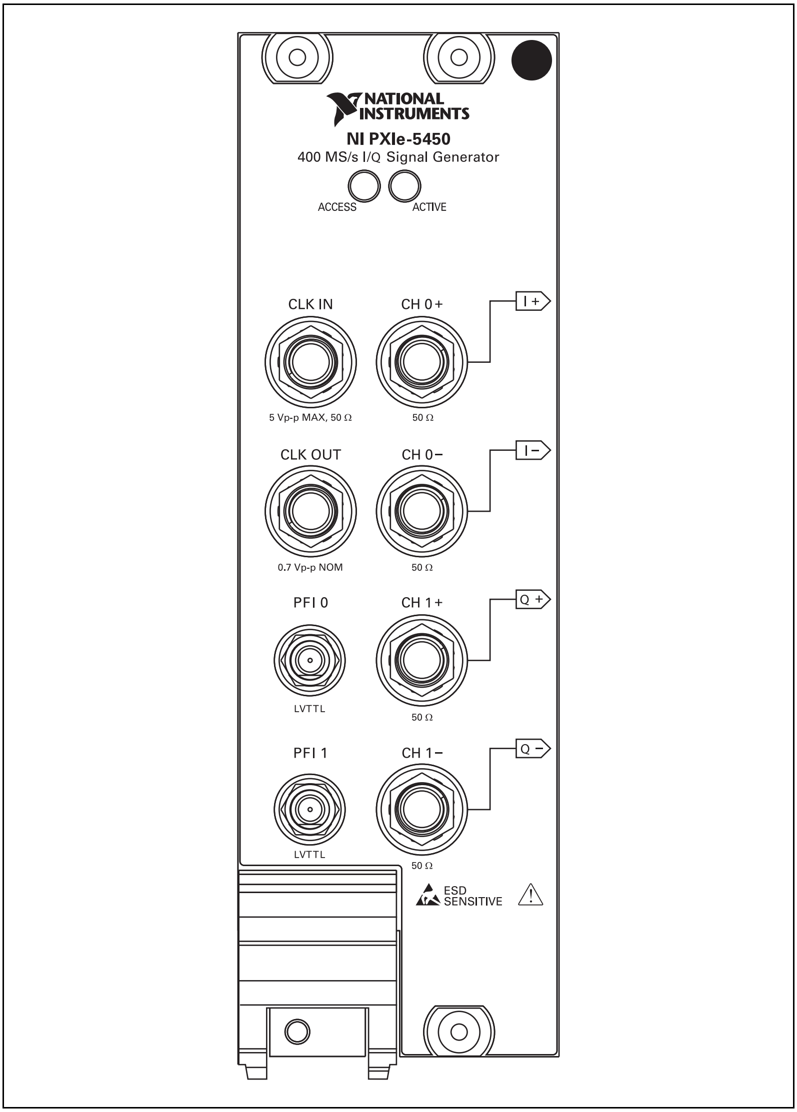


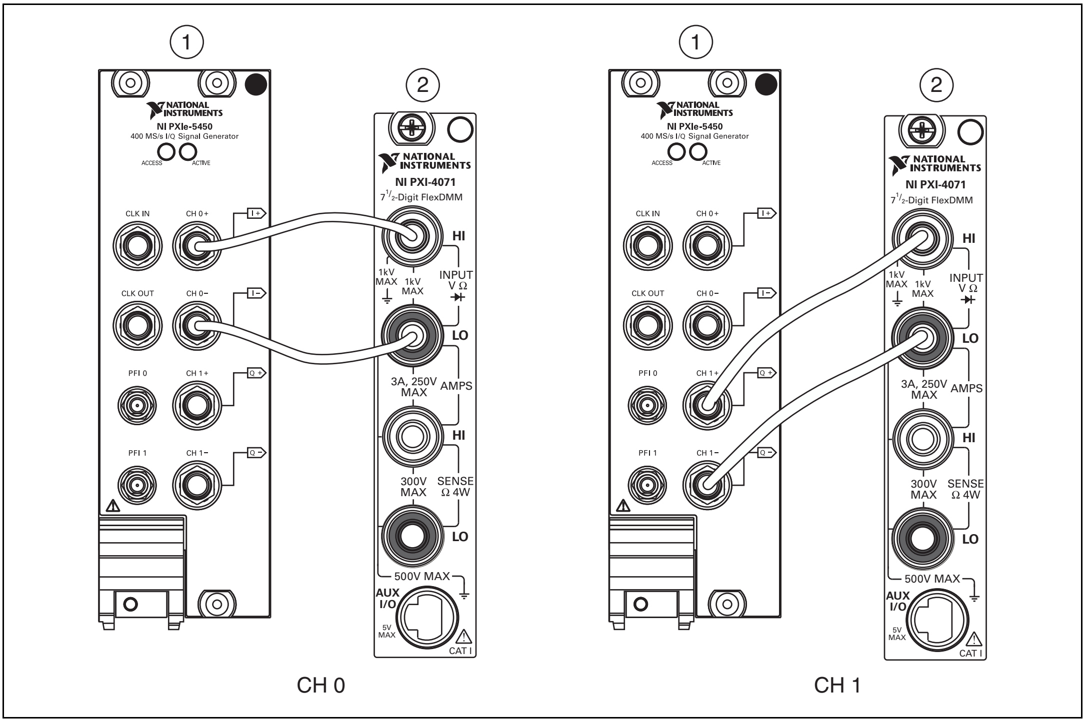
Figure 1. NI PXIe-5450 Front Panel

Verifying DC Voltage Amplitude Absolute Accuracy

Complete the following steps to verify the DC voltage amplitude absolute accuracy of an NI 5450 module using a digital multimeter (DMM).

1. Connect the DMM to the CH 0 output terminals of the NI 5450 as shown in Figure 2.

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



1 NI PXIe-5450	2 NI PXI-4071

Figure 2. DC Voltage Amplitude Absolute Accuracy Verification Connections for the NI 5450

2. Configure the DMM according to Table 2 for the appropriate NI 5450 output voltage from Table 3.

Table 2. Calibration Equipment Configuration for DC Amplitude Absolute Accuracy Verification

NI 5450			DMM			
Configuration	**CH**	**Output (V)**	**Function**	**Range (V)***	**Input Impedance (GΩ)***	**Average Readings**
1	0, 1	+0.1, –0.1	DC Voltage	0.1	10	4
2	0, 1	+1.0, –1.0 +0.5, –0.5	DC Voltage	1	10	4

* 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. Configure the NI 5450 for the appropriate configuration in Table 3.

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

Table 3. NI 5450 Output Parameters Configuration and Test Limits for DC Amplitude Absolute Accuracy Verification

Config.	CH	Differential Output Range ($V_{pk\text{-}pk}$)	Gain	Error*	Load Impedance (GΩ)	Waveform Data Amplitude (V)	As Found Test Limit (V)	After Adjustment Test Limit (V)	Measurement Uncertainty (µV)
1	0	2	1	$\varepsilon = V_{DMM} - V_{Expected}$	10	+0.1	± 0.004	± 0.0018	± 4
2					10	+0.5	± 0.004	± 0.0018	± 15
3					10	+1.0	± 0.004	± 0.0018	± 40
4					10	–0.1	± 0.004	± 0.0018	± 4
5					10	–0.5	± 0.004	± 0.0018	± 15
6					10	–1.0	± 0.004	± 0.0018	± 40
7	1				10	+0.1	± 0.004	± 0.0018	± 4
8					10	+0.5	± 0.004	± 0.0018	± 15
9					10	+1.0	± 0.004	± 0.0018	± 40
10					10	–0.1	± 0.004	± 0.0018	± 4
11					10	–0.5	± 0.004	± 0.0018	± 15
12					10	–1.0	± 0.004	± 0.0018	± 40

* Expected is equal to the waveform data amplitude multiplied by gain.

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.
7. Compare the output error to the test limit for the appropriate configuration in Table 3.
8. Repeat steps 2 through 7 for each configuration in Table 3 for CH 0.
9. Set the output voltage level to 0.
10. Connect the DMM to the NI 5450 as shown in Figure 2 for CH 1.
11. Repeat steps 2 through 7 for each configuration in Table 3 for CH 1.
12. Set the output voltage level to 0.

Verifying DC Voltage Differential Offset Accuracy

Complete the following steps to verify the DC voltage differential offset accuracy of an NI 5450 module using a digital multimeter (DMM).

1. Connect the DMM to the CH 0 output terminals of the NI 5450 as shown in Figure 2 for CH 0.
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 5450 to generate a waveform with the following characteristics:
   - Waveform data amplitude: 0 V
   - Load impedance: 10 GΩ
   - Gain: 1
   - Channel: CH 0, CH 1
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 4.

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

Table 4. NI 5450 Output Parameters Configuration and Test Limits for DC Voltage Differential Offset Accuracy Verification

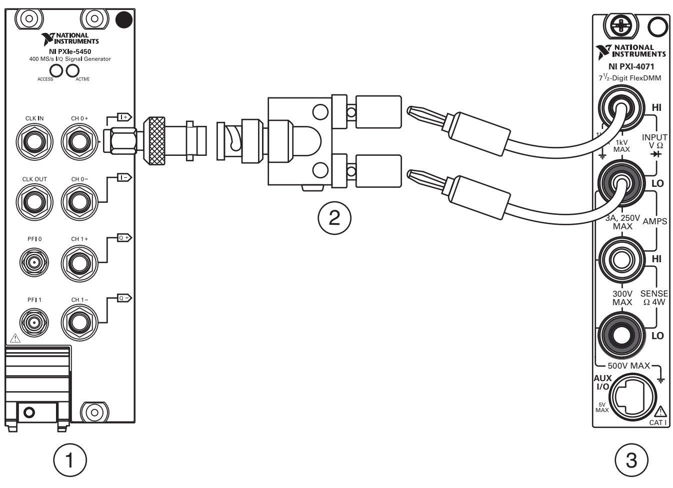
Config.	CH	Differential Output Range ($V_{pk\text{-}pk}$)	Gain	Load Impedance (GΩ)	Waveform Data Amplitude (V)	As Found Test Limit (mV)	After Adjustment Test Limit (mV)	Measurement Uncertainty (µV)
1	0	2	1	10	+0.0	± 1.0	± 0.75	± 3.0
2	1	2	1	10	+0.0	± 1.0	± 0.75	± 3.0

7. Connect the DMM to the CH 1 output terminals of the NI 5450 as shown in Figure 2 for CH 1.
8. Repeat steps 3 through 6 for CH 1.

Verifying DC Voltage Common Mode Offset Accuracy

Complete the following steps to verify the DC voltage common mode offset accuracy of an NI 5450 module using a digital multimeter.

1. Connect the NI 5450 CH 0+ output to the positive output of the DMM and the cable shield ground of the NI 5450 CH 0+ output to the negative input of the DMM as shown in Figure 3.



1 NI PXIe-5450	2 Dual banana plug	3 NI PXI-4071

Figure 3. DC Voltage Common Mode Offset Accuracy Verification Connection (CH 0)

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. Set up the NI 5450 according to Table 5.

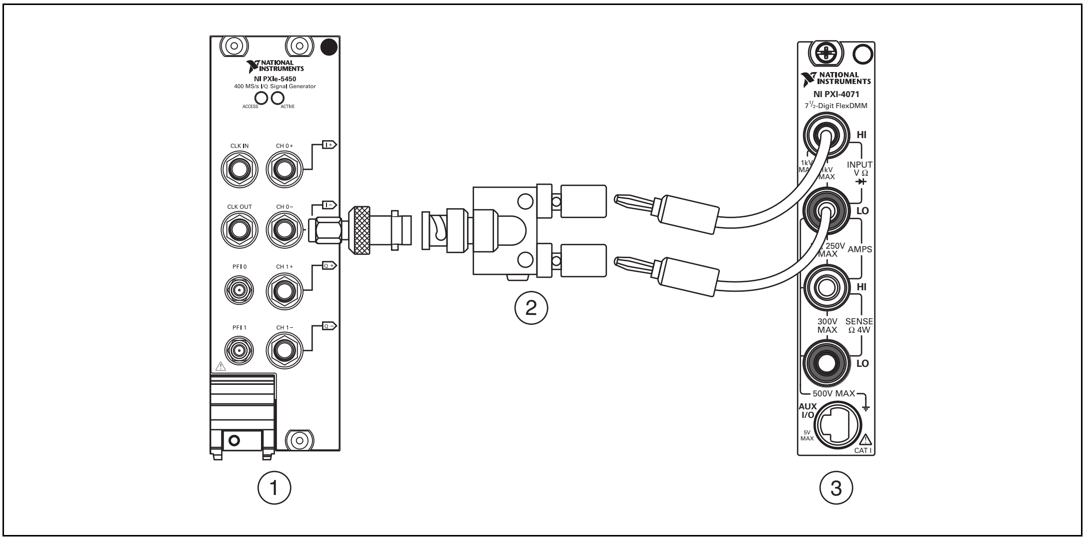
Note Refer to the *Measurement Uncertainty* section for more information on the measurement uncertainty calculation in the following table.

Table 5. NI 5450 Output Parameters Configuration and Test Limits for DC Voltage Common Mode Offset Accuracy

CH	Load Impedance (GΩ)	Waveform Data Amplitude (V)	Gain	Error (V)	As Found Test Limit (μV)	After Adjustment Test Limit (μV)	Measurement Uncertainty (μV)
0, 1	10	0.0 V	1	$\varepsilon_{V_{CMO}} = \frac{(V_{CMO(+)} + V_{CMO(-)})}{2}$	±350	±250	±1.3

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 5450 CH 0- output to the positive output of the DMM and the cable shield ground of the NI 5450 CH 0- output to the negative input of the DMM as shown in Figure 4.

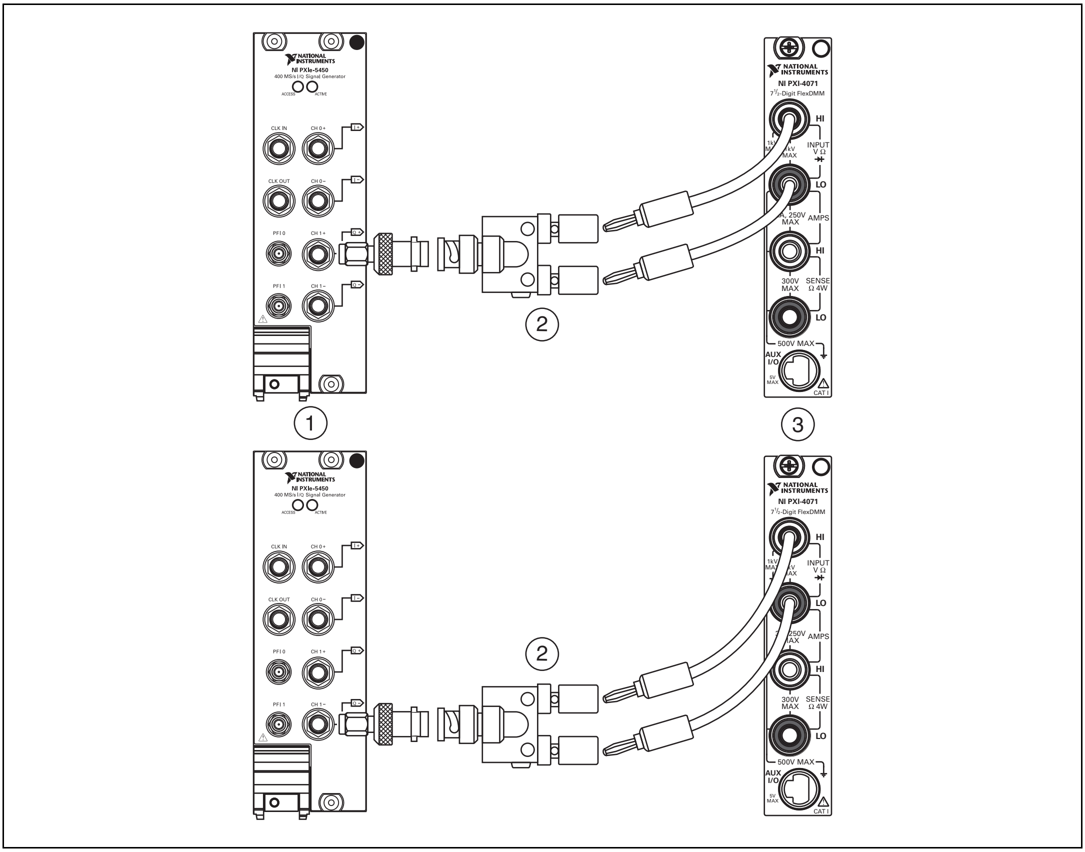


1	NI PXIe-5450	2	Dual banana plug	3	NI PXI-4071

Figure 4. 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 5 and compare it to the test limit.

10. Repeat steps 1 through 9, replacing CH 0 with CH 1. The connections are shown in Figure 5.



1 NI PXIe-5450	2 Dual banana plug	3 NI PXI-4071

Figure 5. DC Voltage Common Mode Offset Accuracy Verification Connections (CH 1)

Verifying DC Voltage Channel-to-Channel Relative Accuracy

Using the values recorded in step 6 of the *Verifying DC Voltage Amplitude Absolute Accuracy* section, calculate the DC voltage channel-to-channel relative accuracy for each configuration in Table 6.

Note The values are calculated using the measurements recorded in Table 3.

Note Refer to the *Measurement Uncertainty* section for more information on the measurement uncertainty calculations in the following table.

Table 6. DC Amplitude Channel-to-Channel Relative Accuracy Verification

Configuration	CH	Waveform Data Amplitude (V)	Error (V)	Test Limit (µV)	Measurement Uncertainty (µV)
1	0, 1	+0.1	$\varepsilon_{0,1} = V_{CH0} - V_{CH1}$	±1600	±20
2	0, 1	+0.5		±1600	±20
3	0, 1	+1.0		±1600	±20
4	0, 1	–0.1		±1600	±20
5	0, 1	–0.5		±1600	±20
6	0, 1	–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 5450 module using a digital multimeter (DMM).

1. Connect the DMM to the NI 5450 as shown in Figure 2 for CH 0.
2. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Frequency: 50 kHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Load impedance: 10 MΩ
   - Gain: 1
   - Channel: CH 0, CH 1

3. 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.

4. Configure the NI 5450 for the appropriate configuration in Table 7.

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

Table 7. NI 5450 Output Parameters Configuration and Test Limits for AC Amplitude Accuracy Verification

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

* Full scale for waveform data amplitude is ±1.

5. Wait 15 seconds for the output of the NI 5450 to settle.
6. Measure the output voltage amplitude with the DMM.
7. Record the V_{RMS} measurement.
8. Calculate the peak-to-peak amplitude error using the equation in Table 7.
9. Compare the output error to the test limit for the appropriate configuration in Table 7.
10. Set the output voltage level to 0.
11. Connect the DMM to the NI 5450 as shown in Figure 2 for CH 1.
12. Repeat steps 2 through 10 for Configuration 2 of Table 7 for CH 1.

Verifying AC Amplitude Channel-to-Channel Relative Accuracy

Complete the following steps to verify the AC amplitude channel-to-channel relative accuracy of an NI 5450 module.

1. Use the values recorded in step 7 of the *Verifying AC Voltage Amplitude Absolute Accuracy* section to calculate the AC amplitude channel-to-channel relative accuracy using the equation in Table 8.

Note Refer to the *Measurement Uncertainty* section for more information on the measurement uncertainty calculations in the following table.

Table 8. AC Amplitude Channel-to-Channel Relative Accuracy Verification

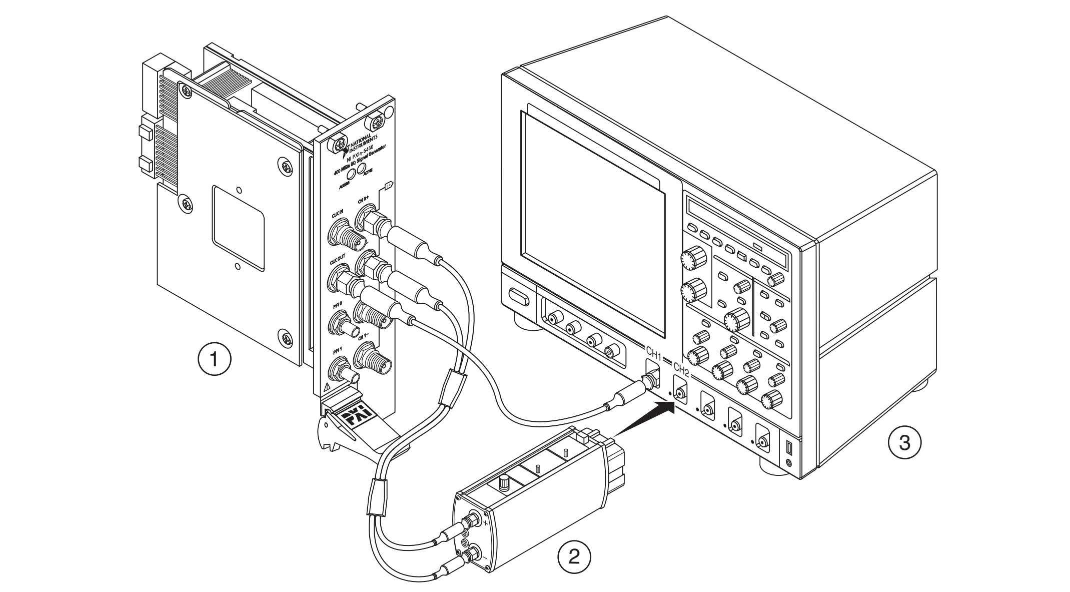
CH	Gain	Differential Output Range (V_{pk-pk})	Error (mV_{pk-pk})	Test Limit (mV_{pk-pk})	Measurement Uncertainty (mV_{pk-pk})
0, 1	1	2.0	$\varepsilon_{0,1} = 2 \times \sqrt{2} \times (V_{RMS_{CH0}} - V_{RMS_{CH1}})$	±4.0	±0.2

2. Compare the output error to the Test Limit in Table 8.

Verifying Channel-to-Channel Timing Alignment Accuracy

Complete the following steps to verify the channel-to-channel timing alignment accuracy of an NI 5450 module using a digital oscilloscope and a differential acquisition probe.

1. Connect the devices as shown in Figure 6.



1 NI 5450 Signal Generator	3 Tektronix DPO70404 Digital Oscilloscope
2 Tektronix P7380SMA Differential Probe	

Figure 6. NI 5450 Connection to an Oscilloscope Using a Differential Acquisition Probe (CH 0)

Note Use the cables that are included with the oscilloscope for the connections to the NI 5450. When changing the connections from CH 0 to CH 1 in step 14, maintain the same relative cable position.

2. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform: Square wave
   - Frequency: 10 MHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude: 0 dBFS
   - Gain setting: 0.5

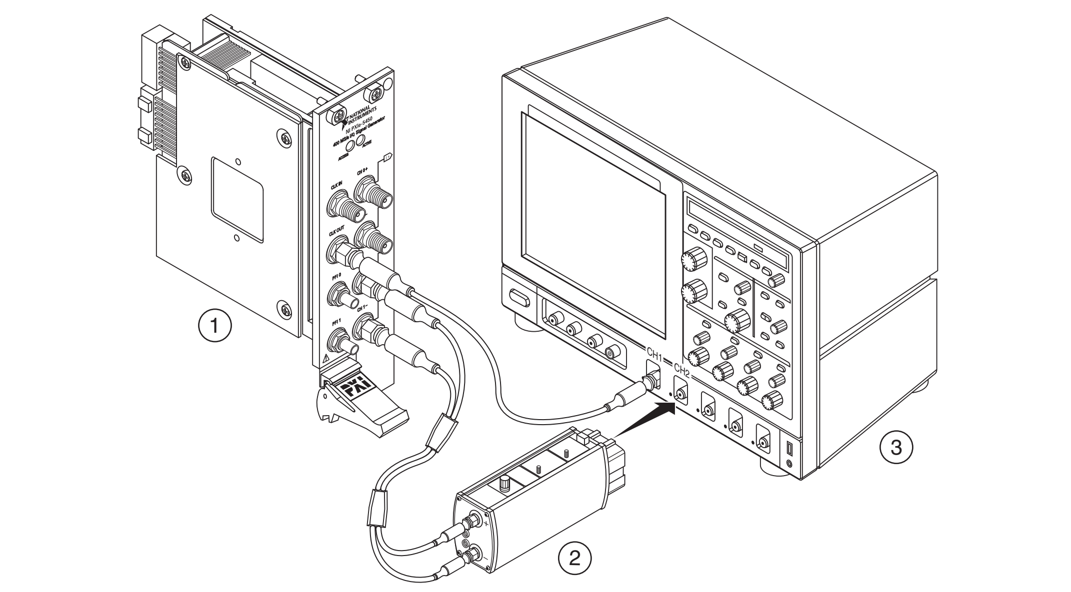
- Load impedance: 50 Ω
- Output channel: CH 0, CH 1 (simultaneous)
- Exported sample clock timebase divisor: 40
- Sample clock timebase export location: Clkout

Note Both NI 5450 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.

Configure the oscilloscope according to the following steps:

3. Run DEFAULT SETUP to set the oscilloscope to a known state.
4. Enable CH 1 and CH 2 on the oscilloscope.
5. Run AUTOSET to acquire CH 1 and CH 2 waveforms.
6. Set the oscilloscope to trigger continuously on the rising edge of CH 1.
7. Set the acquisition mode to average 256 samples.
8. Center the rising edge of the CH 2 waveform in the center of the oscilloscope display by using HORIZONTAL DELAY.
9. Adjust the oscilloscope vertical scale of CH 2 to maximum while keeping the waveform within the display, approximately 125 mV/div.
10. Set the timebase to 1 ns/div and use HORIZONTAL DELAY to keep the CH 2 rising edge centered in the oscilloscope display.
11. Set the scale resolution to 1 ps/pt.
12. Clear the acquisition averages and then wait for 256 acquisitions to occur.
13. Save the CH 2 waveform as REF1 (NI 5450, CH 0).

14. Connect the devices as shown in Figure 7.



1	NI 5450 Signal Generator	3	Tektronix DPO70404 Digital Oscilloscope
2	Tektronix P7380SMA Differential Probe		

Figure 7. NI 5450 Connection to an Oscilloscope Using a Differential Acquisition Probe (CH 1)

15. Clear the waveform averages.
16. The rising edge of the NI 5450 CH 1 output waveform should now be in the center of the oscilloscope display.
17. Recall the CH 2 output waveform previously saved as REF1 (NI 5450, CH 0) in step 13.
18. Set the oscilloscope to measure the delay between REF1 (NI 5450, CH 0) and the current CH 2 input (NI 5450, CH 1). The measurement should be rising to rising edge at 50% amplitude.
19. Wait for the measurement counter to reach at least 50 before the reading is made.
20. Measure and record the mean value.

21. Compare the delay value with the Test Limit in Table 9.

Table 9. Channel-to-Channel Timing Alignment Accuracy Verification

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

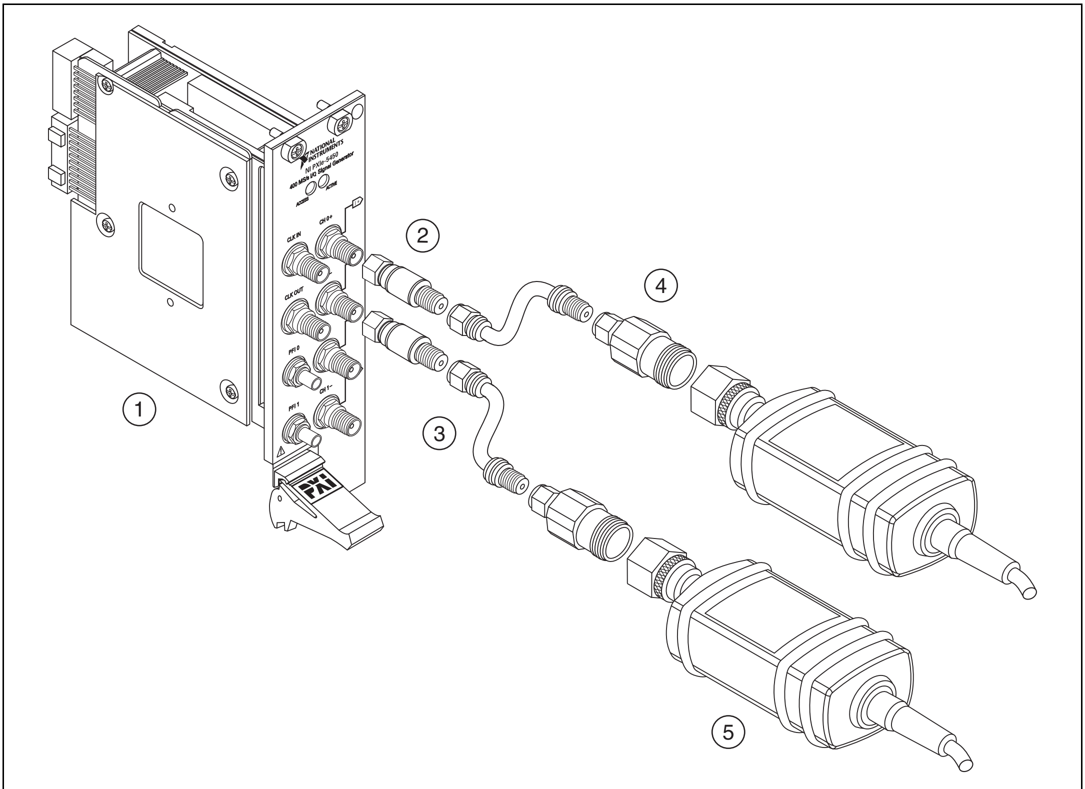
* Both NI 5450 channels must be enabled simultaneously during this test. If the session is disabled or restarted at any point during the test, the measurements are invalid.

Verifying Frequency Response (Flatness)

Complete the following steps to verify the frequency response (flatness) of an NI 5450 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.

1. Connect the devices as shown in Figure 8, using semi-rigid coaxial cables to connect the power meters simultaneously if needed.



1	NI 5450 Signal Generator	4	N-Type 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 8. NI 5450 Connection to Power Meters Using Attenuators (CH 0)

2. Disable the NI 5450 outputs.
3. Null the power meter(s) according to the power meter documentation.
4. Configure the power meter(s) with the following characteristics:
   - Multichannel
   - Average: 16
   - Measure watts
   - Channel 1 power sensor connected to the NI 5450(+)
   - Channel 2 power sensor connected to the NI 5450(–)
   - High accuracy

5. Configure the NI 5450 according to Configuration 1 in Table 10.

Table 10. NI 5450 Setup for Frequency Response (Flatness) Verification

Config.	CH	Function	Waveform Amplitude	Gain	Flatness Correction	Waveform Sample	Differential Load*
1	0, 1	Sine wave	0 dBFS	0.4	Enable	400 MS/s	100 Ω
2	0, 1	Sine wave	–20 dBFS	0.4	Enable	400 MS/s	100 Ω

* 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.

6. Configure the NI 5450 and power meter frequency according to Configuration 1 in Table 11, the reference frequency.

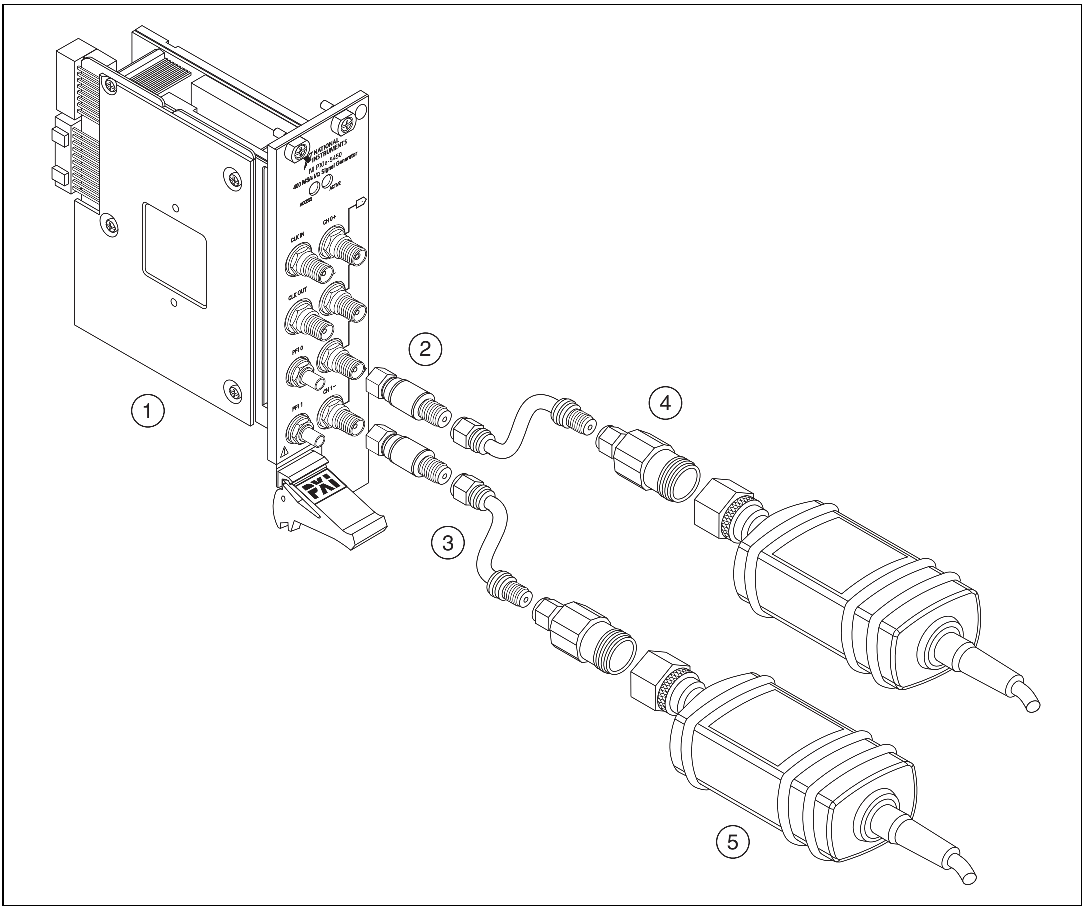
Table 11. Frequency Response (Flatness) Verification

Config.	CH	Frequency	Frequency Response (Flatness)*	As Found Test Limit	After Adjustment Test Limit	Measurement Uncertainty
1	0, 1	50 kHz	$Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)} + W_{f(-)} + 2 \times \sqrt{W_{f(+)} \times W_{f(-)}}}{W_{Ref(+)} + W_{Ref(-)} + 2 \times \sqrt{W_{Ref(+)} \times W_{Ref(-)}}}\right]$	Reference	Reference	—
2	0, 1	10 kHz		±0.24 dB	±0.22 dB	0.10 dB
3	0, 1	100 kHz		±0.24 dB	±0.22 dB	0.10 dB
4	0, 1	1 MHz		±0.24 dB	±0.22 dB	0.10 dB
5	0, 1	10 MHz		±0.24 dB	±0.22 dB	0.10 dB
6	0, 1	20 MHz		±0.24 dB	±0.22 dB	0.10 dB
7	0, 1	30 MHz		±0.24 dB	±0.22 dB	0.10 dB
8	0, 1	40 MHz		±0.24 dB	±0.22 dB	0.10 dB
9	0, 1	50 MHz		±0.24 dB	±0.22 dB	0.10 dB
10	0, 1	60 MHz		±0.24 dB	±0.22 dB	0.10 dB
11	0, 1	70 MHz		±0.34 dB	±0.25 dB	0.12 dB
12	0, 1	80 MHz		±0.34 dB	±0.25 dB	0.12 dB
13	0, 1	90 MHz		±0.34 dB	±0.25 dB	0.12 dB
14	0, 1	100 MHz		±0.34 dB	±0.25 dB	0.12 dB
15	0, 1	110 MHz		±0.34 dB	±0.25 dB	0.12 dB
16	0, 1	120 MHz		±0.34 dB	±0.25 dB	0.12 dB

* 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.

7. Allow the power meter to stabilize for 10 seconds.
8. Measure and record the reference (50 kHz) power ($W_{Ref(+)}$ [W]) of the positive output.
9. Measure and record the reference (50 kHz) power ($W_{Ref(-)}$ [W]) of the negative output.
10. Configure the NI 5450 and power meter frequency according to the next configuration in Table 11.
11. Allow the power meter to stabilize for 10 seconds.
12. Measure and record the power at the set frequency ($W_{f(+)}$ [W]) of the positive output.
13. Measure and record the power at the set frequency ($W_{f(-)}$ [W]) of the negative output.
14. Using the recorded power values, calculate the deviation from the reference (50 kHz) power using the equation in Table 11.
15. Compare the *Frequency Response (Flatness)* to the test limit for the appropriate configuration in Table 11.
16. Repeat steps 10 through 15 for each configuration in Table 11.
17. Configure the NI 5450 according to Configuration 2 in Table 10.
18. Repeat steps 7 through 16.

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



1	NI 5450 Signal Generator	4	N-Type 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		

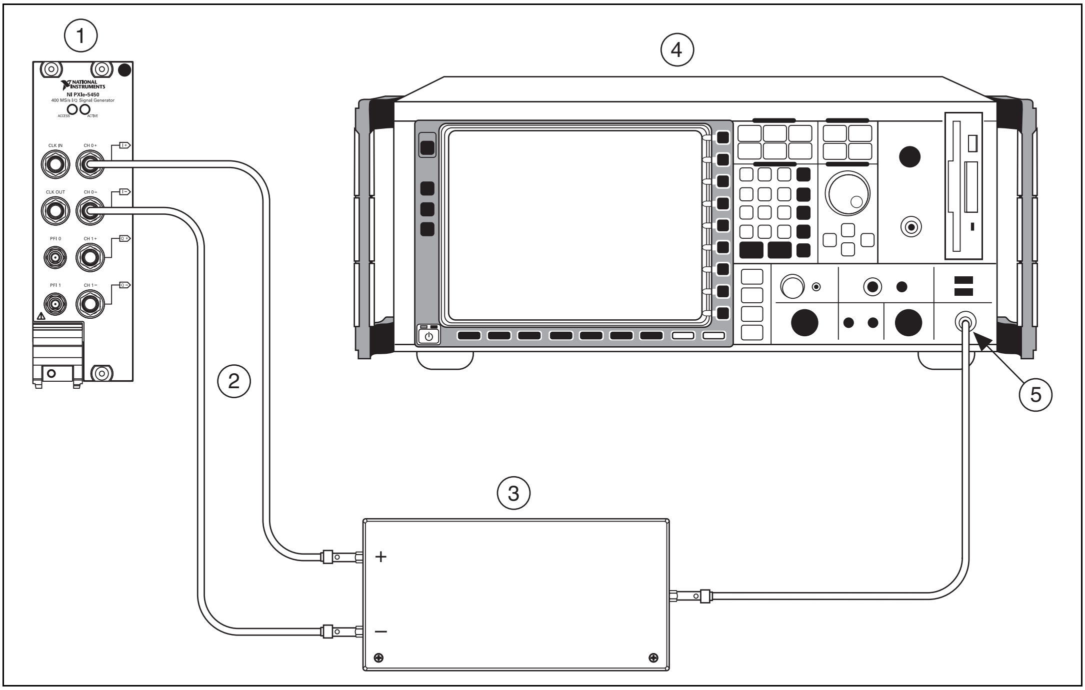
Figure 9. NI 5450 Connection to Power Meters Using Attenuators (CH 1)

20. Repeat steps 5 through 18.

Verifying Average Noise Density

Complete the following steps to verify the average noise density of an NI 5450 module using a spectrum analyzer and BALUN.

1. Connect the devices as shown in Figure 10.



1	NI 5450 signal generator	3	Picosecond 5320B BALUN	5	RF IN connector
2	Matched length cables	4	R&S FSU26 spectrum analyzer		

Figure 10. NI 5450 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. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform: sine wave
   - Frequency: 1 MHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude: –40 dBFS
   - Gain setting: 0.5
   - Load impedance: 50 Ω (100 Ω differential)
   - Output channel: CH 0

3. Set the spectrum analyzer to its default and configure it with the following characteristics:
   - Measurement: Noise marker on
   - Preamplifier: 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

Note Refer to the *Measurement Uncertainty* section for more information on the measurement uncertainty calculations in the following table.

Table 12. Average Noise Density Verification

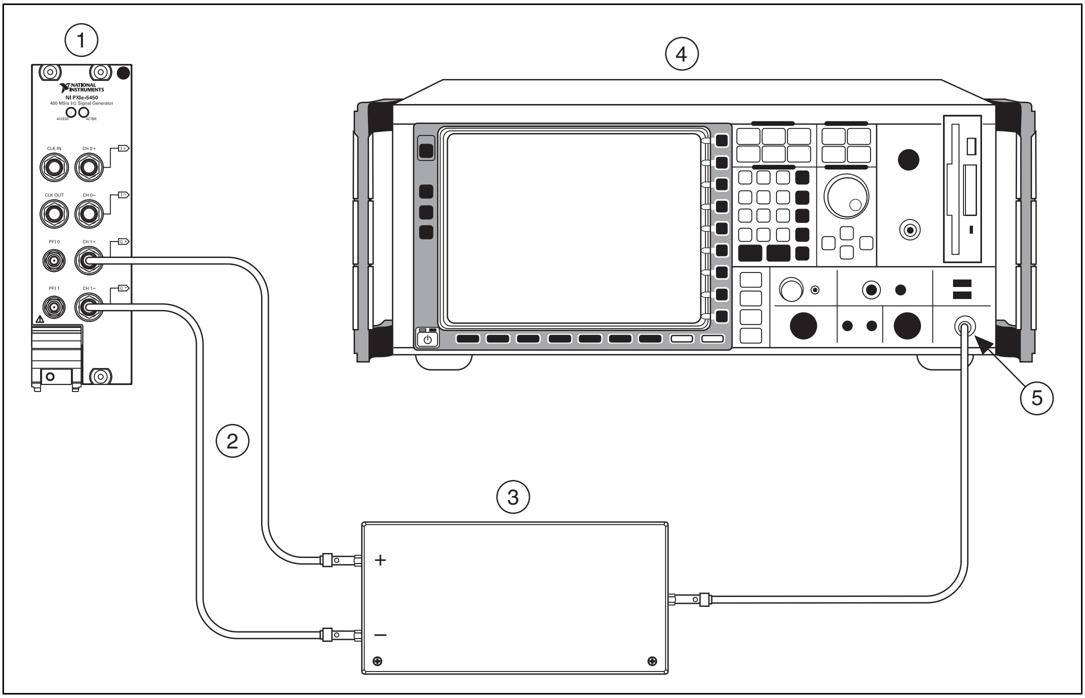
CH	Output Frequency	Average Noise Density (dBm/Hz)	Test Limit (dBm/Hz)	Measurement Uncertainty (dB)
0, 1	0–200 MHz	$AVG\_ND = 20 \times \log_{10}\left(\frac{\sum_{i=1}^{n} 10^{\langle \frac{NoiseDensity(i)}{20} \rangle}}{n}\right)$ Frequency step = 10 MHz, from 10 MHz to 200 MHz	≤ –160	0.60

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 12.
10. Compare the Average Noise Density with the Test Limit in Table 12.

11. Connect the devices as shown in Figure 11.



1	NI 5450 signal generator	3	Picosecond 5320B balun	5	RF IN connector
2	Matched length cables	4	R&S FSU26 spectrum analyzer		

Figure 11. NI 5450 Connection to Spectrum Analyzer Using a BALUN (CH 1)

12. Repeat steps 4 through 10.

Verifying Internal Reference Clock Frequency Accuracy

Complete the following steps to verify the internal reference clock frequency accuracy of an NI 5450 module using a spectrum analyzer and BALUN.

1. Connect the devices as shown in Figure 10.
2. Verify that the NI 5450 is not locked to an external clock and is using the onboard clock.
3. Configure the NI 5450 to generate a waveform with the following characteristics:
    - Waveform: Sine wave
    - Frequency: 10 MHz
    - Sample rate: 400 MS/s

- Waveform data amplitude: 0.0 dBFS
- Gain setting: 0.5
- Load impedance: 50 Ω (100 Ω differential)
- Output channel: CH 0

4. 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
5. Measure and record the frequency (fmeas) as displayed on MARKER1.
6. Compare the frequency measured with the test limit in Table 13.

Note Refer to the *Measurement Uncertainty* section for more information on the measurement uncertainty calculations in the following table.

Table 13. Internal Reference Clock Accuracy Verification

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

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 5450 module.

1. Use the values calculated in the *Verifying Frequency Response (Flatness)* section to calculate the channel-to-channel frequency response (flatness) matching accuracy.

Table 14. Channel-to-Channel Frequency Response (Flatness) Matching Accuracy Verification

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

Verifying Analog Bandwidth

Complete the following steps to verify the analog bandwidth of an NI 5450 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.

1. Connect the devices as shown in Figure 8, using semi-rigid coaxial cables to connect the power meters simultaneously if needed.
2. Configure the power meter(s) with the following characteristics:
   - Multichannel
   - Average: 16
   - Measure watts
   - High accuracy
3. Disable the NI 5450 output and null the power meter(s) according to the power meter documentation.
4. Configure the NI 5450 with the following characteristics:
   - Waveform: Sine wave
   - Sample rate: 400 MS/s
   - Waveform data amplitude: 0 dBFS
   - Gain setting: 0.5
   - Load impedance: 50 Ω (100 Ω differential)
   - Flatness correction: Disabled
   - Output channel: CH 0 and CH 1
5. Configure the NI 5450 and power meter frequency according to Configuration 1 in Table 15, the reference frequency.

Table 15. Analog Bandwidth Verification

Config.	CH	Frequency	Frequency Response*	Test Limit (dB), typical
1	0, 1	50 kHz	Reference	—
2	0, 1	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 dB
3	0, 1	140 MHz		≥ –2.75 dB
4	0, 1	145 MHz		≥ –3 dB

* 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.

6. Allow the power meter to stabilize for 10 seconds.
7. Measure and record the reference power ($W_{Ref(+)}$ [W]) of the positive output.
8. Measure and record the reference power ($W_{Ref(-)}$ [W]) of the negative output.
9. Configure the NI 5450 and power meter frequency according to the next configuration in Table 15.
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 at 50 kHz using the equation in Table 15.
13. Compare the frequency response (flatness) to the Test Limit for the appropriate configuration in Table 15.
14. Repeat steps 9 through 13 for each configuration in Table 15.

Verifying Spurious Free Dynamic Range with and without Harmonics

Complete the following steps to verify the spurious free dynamic range (SFDR) with harmonics of an NI 5450 module using a spectrum analyzer and BALUN.

1. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Frequency: 10 MHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude: –1 dBFS
   - Gain setting: 0.5
   - Load impedance: 50 Ω (100 Ω differential)
   - Output channel: CH 0 and CH 1
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

Table 16. Spurious Free Dynamic Range Accuracy Verification

Config.	CH	Carrier Frequency (MHz)	Spurious Free Dynamic Range (dB)	Test Limit (dB), typical
1	0, 1	10	$SFDR_{\text{With Harmonics}}$ = Ampl(carrier) – Ampl(LargestSpur)	≥70
2	0, 1	10	$SFDR_{\text{Without Harmonics}}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥70
3	0, 1	60	$SFDR_{\text{With Harmonics}}$ = Ampl(carrier) – Ampl(LargestSpur)	≥68
4	0, 1	60	$SFDR_{\text{Without Harmonics}}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥68
5	0, 1	100	$SFDR_{\text{With Harmonics}}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
6	0, 1	100	$SFDR_{\text{Without Harmonics}}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥64
7	0, 1	120	$SFDR_{\text{With Harmonics}}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
8	0, 1	120	$SFDR_{\text{Without Harmonics}}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62
9	0, 1	160	$SFDR_{\text{With Harmonics}}$ = Ampl(carrier) – Ampl(LargestSpur)	≥62
10	0, 1	160	$SFDR_{\text{Without Harmonics}}$ = Ampl(carrier) – Ampl(Non-harmonic LargestSpur)	≥62

3. Connect the devices as shown in Figure 10.
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 16 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 16 for the carrier frequency.
13. Change the NI 5450 output frequency (carrier) to the next Test in Table 16 and repeat steps 4 through 12.
14. Reset the average.
15. Repeat steps 4 through 14 for all carrier frequencies in Table 16.
16. Connect the devices as shown in Figure 11.
17. Repeat steps 4 through 15 for CH 1.

Verifying Total Harmonic Distortion

Complete the following steps to verify the total harmonic distortion (THD) of an NI 5450 module using a spectrum analyzer and BALUN.

1. Connect the devices as shown in Figure 10.
2. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform: Sine wave
   - Frequency: 10.1 MHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude: –1 dBFS
   - Gain setting: 0.5
   - Load impedance: 50 Ω (100 Ω differential)
   - Output channel: CH 0 and CH 1
3. Set the spectrum analyzer to its default and configure it with the following characteristics:
   - Frequency range: 10.1 MHz
   - 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

Table 17. Total Harmonic Distortion Accuracy Verification

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

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.
10. Disable the HARMONIC measure function.
11. Change the NI 5450 output frequency and the spectrum analyzer center frequency to the next Carrier Frequency value in Table 17.
12. Repeat steps 4 through 11 for all the carrier frequencies in Table 17.
13. Connect the devices as shown in Figure 11.
14. Repeat steps 4 through 12 for CH 1.

Verifying Intermodulation Distortion (IMD_3)

Complete the following steps to verify the intermodulation distortion of an NI 5450 module using a spectrum analyzer and BALUN.

1. Connect the devices as shown in Figure 10.
2. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform:
     - Tone Frequency 1: 9.9 MHz
     - Tone Frequency 2: 10.1 MHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude (each tone): –7 dBFS
   - Gain Setting: 0.5
   - Load Impedance: 50 Ω (100 Ω differential)
   - Output channel: CH 0
3. Configure the spectrum analyzer with the following characteristics:
   - Frequency range: 10 MHz
   - 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

Table 18. Intermodulation Distortion (IMD_3) Verification Setup

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	$Max(P_{\langle 2 \times f_2 - f_1 \rangle}, P_{\langle 2 \times f_1 - f_2 \rangle}) - Min(P_{f_1}, P_{f_2})$	≤ –84
2	0, 1	19.9	20.1	20		≤ –81
3	0, 1	39.9	40.1	40		≤ –75
4	0, 1	59.9	60.1	60		≤ –71
5	0, 1	79.9	80.1	80		≤ –68
6	0, 1	119.9	120.1	120		≤ –68
7	0, 1	159.9	160.1	160		≤ –66

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.

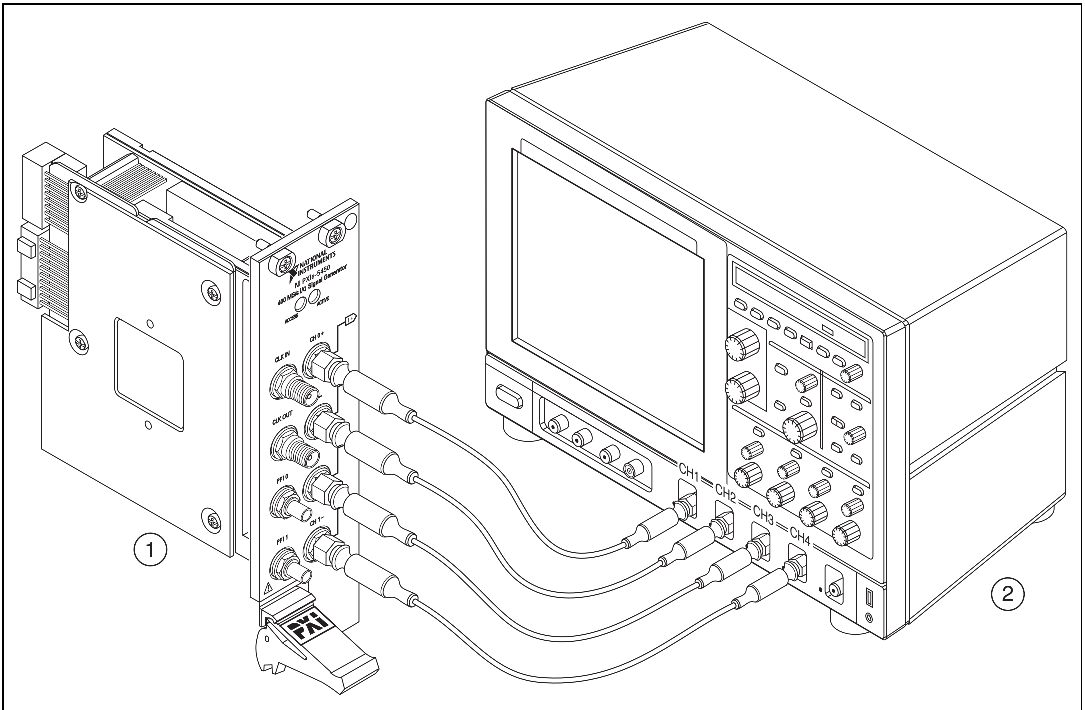
Note Incorrect attenuation on the spectrum analyzer can severely affect the IMD_3 measurement. Refer to the spectrum analyzer documentation for more information.

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 18 to calculate the IMD_3.
8. Change the NI 5450 output frequency to the next carrier tone frequencies as indicated in Table 18.
9. Change the spectrum analyzer CENTER FREQUENCY to the adequate value indicated in Table 18.
10. Repeat steps 4 through 9 for all carrier frequencies in Table 18.

Verifying Rise and Fall Time

Complete the following steps to verify the rise time and fall time of an NI 5450 module using an oscilloscope.

1. Connect the devices as shown in Figure 12.



1 NI PXIe-5450	2 Tektronix DPO70404 Oscilloscope

Figure 12. NI 5450 Connection to the Oscilloscope (CH 0 and CH 1)

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

2. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform: Square wave
   - Frequency: 33 MHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Gain setting: 0.5

- Load impedance: 50 Ω
- Output channel: CH 0, CH 1
- Flatness correction: Disabled

3. Configure the oscilloscope according to the following steps:
   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
   d. Configure the oscilloscope as follows:
      - 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.
4. Configure the oscilloscope measurements as follows:
   - CH1 Time function: Rise Time (10% to 90%)
   - CH1 Time function: Fall Time (10% to 90%)
5. Wait for the measurement counter to reach at least 50 before making the reading.

Table 19. Rise and Fall Time Verification

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

6. Read and record the CH1 RISE mean as the Rise Time measurement.
7. Read and record the CH1 FALL mean as the Fall Time measurement.
8. Repeat steps 4 through 7, configuring the measurements for channels 2, 3, and 4.

Verifying Aberrations

Complete the following steps to verify the aberrations of an NI 5450 module using an oscilloscope.

1. Connect the devices as shown in Figure 12.
2. Configure the NI 5450 to generate a waveform with the following characteristics:
   - Waveform: Trapezoidal
   - Slew rate: 133 V/µs
   - Frequency: 10 MHz
   - Sample rate: 400 MS/s
   - Waveform data amplitude: 1 V_{pk} (2 V_{pk-pk})
   - Gain setting: 0.5
   - Load impedance: 50 Ω
   - Output channel: CH 0, CH 1
   - Flatness correction: Disabled

Note To limit the slew rate to 133 V/µs, create 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. Configure the oscilloscope according to the following steps:
   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
   d. Configure the oscilloscope as follows:
      - 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: 10 ns/div

      One complete waveform period should be displayed for each output terminal.

4. Configure the oscilloscope measurements as follows:
   - CH 1 Amplitude: Positive Overshoot
   - CH 1 Amplitude: Negative Overshoot
5. Wait for the measurement counter to reach at least 64 before making the reading.
6. Read and record the channel 1 positive overshoot mean as the rising edge aberration measurement.
7. Read and record the channel 1 negative overshoot mean as the falling edge aberration measurement.
8. Repeat steps 4 through 7, configuring the measurements for channels 2, 3, and 4.

Table 20. Aberration Time Verification

Test	CH	Specification	Test Limit, typical
1	0+, 0–, 1+, 1–	Rising Edge Aberration	≤ 7%
2	0+, 0–, 1+, 1–	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 5450 using a phase noise analyzer and BALUN.

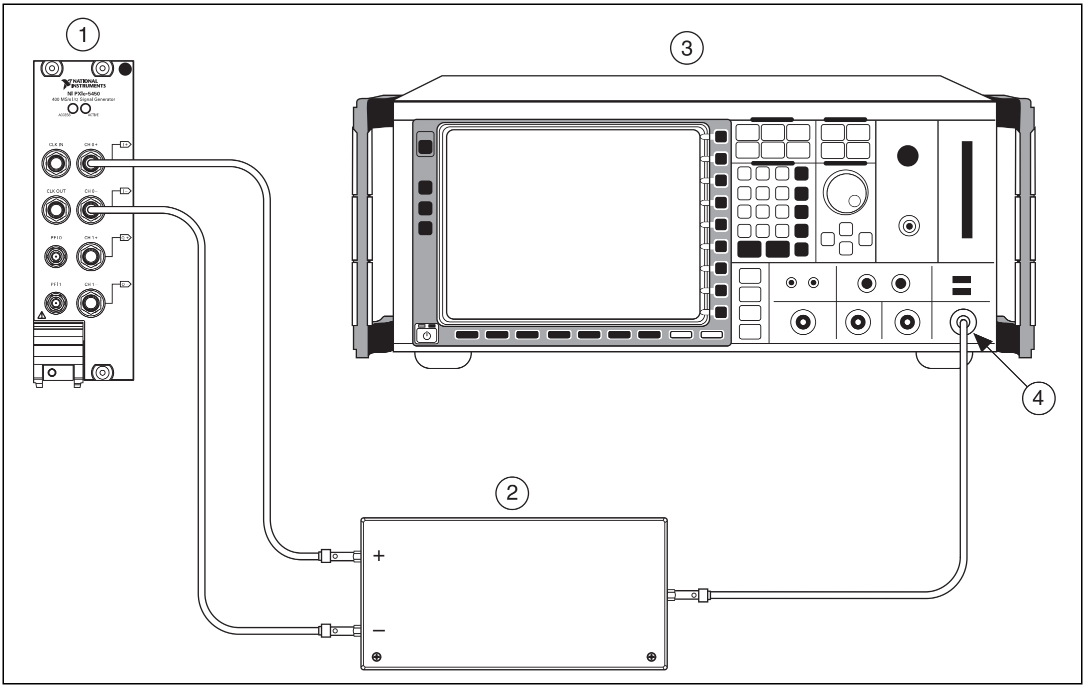
1. Set the phase noise analyzer to its default and configure it with the following characteristics:
   - Measurement mode: Phase noise
   - Center frequency: 10 MHz
   - Level: 0 dBm
   - Spot noise offset frequencies: Refer to Table 21
   - Sweep mode: Normal
   - Frequency span: 100 Hz to 1 MHz

Table 21. 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

Phase Noise Measurements (CH 0, 10 MHz)

1. Connect the devices as shown in Figure 13.



1 NI PXIe-5450	3 R&S FSUP Phase Noise Analyzer
2 Picosecond 5320B BALUN	4 RF IN Connector

Figure 13. NI 5450 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. Configure the NI 5450 according to configuration 1 in Table 22 and enable output.

Table 22. NI 5450 Setup for Phase Noise Density Verification

Config.	CH	Function	Waveform Data Amplitude	Output Frequency	Waveform Sample Rate	Reference Clock	Gain	Differential Load*
1	0	Sine wave	0 dBFS	10 MHz	400 MS/s	Internal	0.5	100 Ω
2	0	Sine wave	0 dBFS	100 MHz	400 MS/s	Internal	0.5	100 Ω
3	1	Sine wave	0 dBFS	100 MHz	400 MS/s	Internal	0.5	100 Ω
4	1	Sine wave	0 dBFS	10 MHz	400 MS/s	Internal	0.5	100 Ω

* 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.

3. Take a new phase noise measurement.
4. Record the 10 MHz output "Spot Noise" readings.
5. Compare the readings to the appropriate *Output Frequency* in Table 24.

Jitter Measurements (CH 0, 10 MHz)

1. Set the phase noise analyzer start frequency to 100 Hz.
2. Set the phase noise analyzer span stop frequency to 100 kHz.
3. Take a new phase noise measurement.
4. Record the CH 0, 100 MHz RMS jitter reading.
5. Compare the readings to the appropriate *Output Frequency* in Table 23.

Phase Noise Density Measurements (CH 0, 100 MHz)

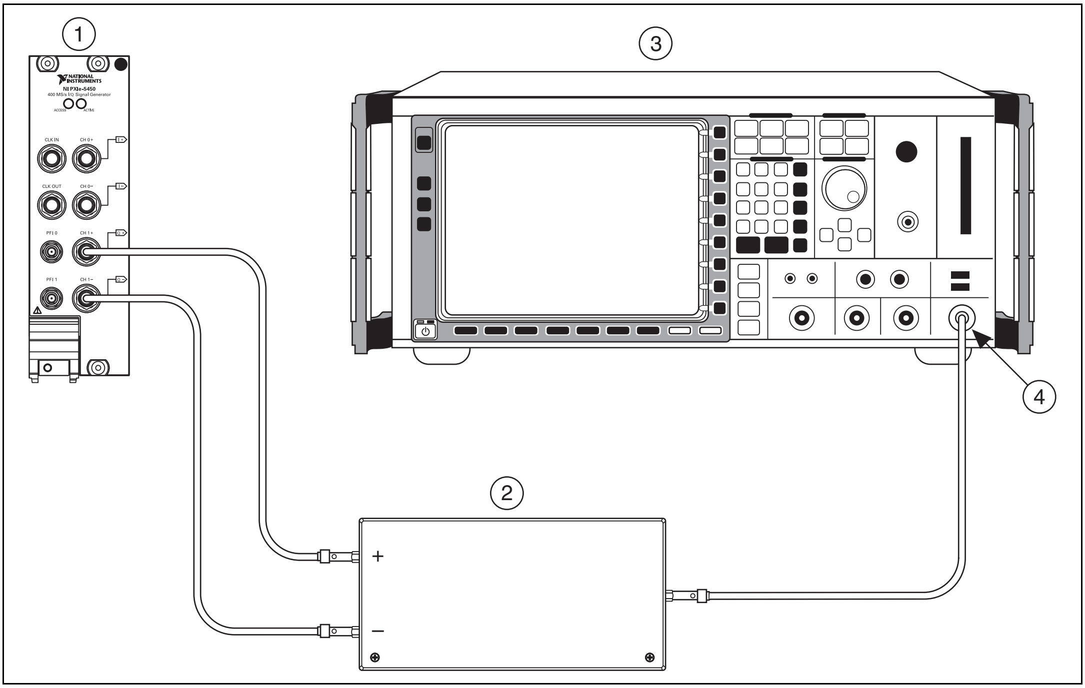
1. Configure the NI 5450 according to configuration 2 in Table 22.
2. Set the phase noise analyzer center frequency to 100 MHz.
3. Set the phase noise analyzer span stop frequency to 1 MHz.
4. Take a new phase noise measurement.
5. Record the 100 MHz output "Spot Noise" readings.
6. Compare the readings to the appropriate *Output Frequency* in Table 24.

Jitter Measurements (CH 0, 100 MHz)

1. Set the phase noise analyzer start frequency to 100 Hz.
2. Set the phase noise analyzer span stop frequency to 100 kHz.
3. Take a new phase noise measurement.
4. Record the CH 0, 100 MHz RMS jitter reading.
5. Compare the readings to the appropriate *Output Frequency* in Table 23.

Phase Noise Density Measurements (CH 1, 100 MHz)

1. Connect the devices as shown in Figure 14.



1	NI PXIe-5450	3	R&S FSUP Phase Noise Analyzer
2	Picosecond 5320B BALUN	4	RF IN Connector

Figure 14. NI 5450 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.

2. Configure the NI 5450 according to configuration 3 in Table 22.
3. Set the phase noise analyzer span stop frequency to 1 MHz.
4. Take a new phase noise measurement.

5. Record the 100 MHz output “Spot Noise” readings.
6. Compare the readings to the appropriate *Output Frequency* in Table 24.

Jitter Measurements (CH 1, 100 MHz)

1. Set the phase noise analyzer start frequency to 100 Hz.
2. Set the phase noise analyzer span stop frequency to 100 kHz.
3. Take a new phase noise measurement.
4. Record the CH 1, 100 MHz RMS jitter reading.
5. Compare the readings to the appropriate *Output Frequency* in Table 23.

Phase Noise Density Measurements (CH 1, 10 MHz)

1. Configure the NI 5450 according to configuration 4 of Table 22.
2. Set the phase noise analyzer center frequency to 10 MHz.
3. Set the phase noise analyzer span stop frequency to 1 MHz.
4. Take a new phase noise measurement.
5. Record the 10 MHz output “Spot Noise” readings.
6. Compare the readings to the appropriate *Output Frequency* in Table 24.

Jitter Measurements (CH 1, 10 MHz)

1. Set the phase noise analyzer start frequency to 100 Hz.
2. Set the phase noise analyzer span stop frequency to 100 kHz.
3. Take a new phase noise measurement.
4. Record the CH 1, 100 MHz RMS jitter reading.
5. Compare the readings to the appropriate *Output Frequency* in Table 23.

Table 23. Jitter Accuracy Verification

CH	Output Frequency	Integrated Jitter*
0, 1	10 MHz	< 350 fs
0, 1	100 MHz	< 350 fs

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

Table 24. Phase Noise Density Accuracy Verification

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

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 5450.

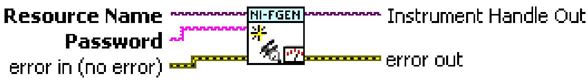
Adjustment corrects the following NI 5450 specifications:

- DC ADC and reference adjustment
- Frequency response (flatness) adjustment

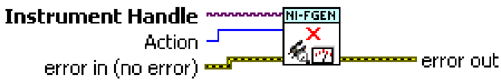
After adjustment, run self-calibration and then repeat the verification section to confirm that the adjustment was successful.

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 DC ADC Reference

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

Note Allow the NI 5450 and support equipment to warm up for a minimum of 30 minutes prior to performing an adjustment.

1. Connect the NI 5450 connector to the DMM as shown in Figure 2 for CH 0. Only CH 0 is used in this adjustment.

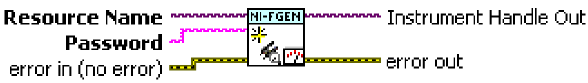
2. Configure the DMM according to Configuration 1 in Table 25.

Table 25. Calibration Equipment Configuration for DC Amplitude Accuracy Adjustment

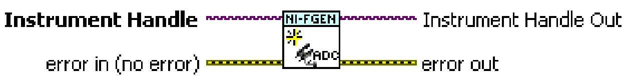
Configuration	Function	Range[*]	Resolution[†]	Average Readings
1	DC Voltage	0.1 V	7.5 digits	10
2	DC Voltage	1 V	7.5 digits	10

[*] 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_Init ExtCal` 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.

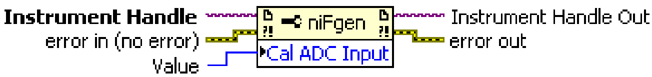
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_InitializeCalADC Calibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

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

<table>
<tr><th>LabVIEW Block Diagram</th><th>C/C++ Function Call</th></tr>
<tr><td>
</td><td>Call <code>niFgen_SetAttribute ViInt32</code> using the following parameters:

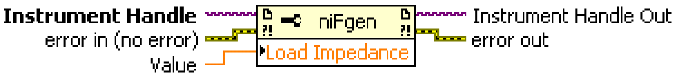
vi: The session handle returned from <code>niFgen_InitExtCal</code>
channelName: <code>NULL</code>
attributeID: <code>NIFGEN_ATTR_GAIN_DAC_ VALUE</code>
value: <code>60948</code></td></tr>
</table>

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

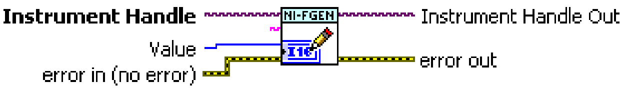
<table>
<tr><th>LabVIEW Block Diagram</th><th>C/C++ Function Call</th></tr>
<tr><td>
</td><td>Call <code>niFgen_SetAttribute ViInt32</code> using the following parameters:

vi: The session handle returned from <code>niFgen_InitExtCal</code>
channelName: <code>NULL</code>
attributeID: <code>NIFGEN_ATTR_CAL_ADC_INPUT</code>
value: <code>NIFGEN_VAL_ANALOG_OUTPUT_ PLUS</code></td></tr>
</table>

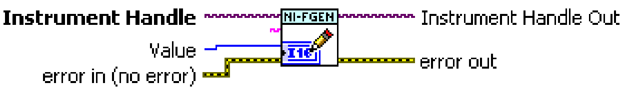
7. Set the output impedance by calling the niFgen Property Node and selecting **Output»Load Impedance**.

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`

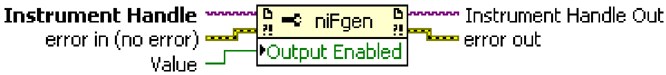
8. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

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`

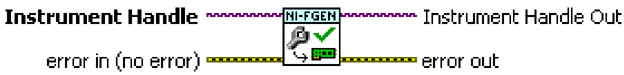
9. Wait 1,000 ms for the output to settle.
10. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value VI.

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**: `3113`

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

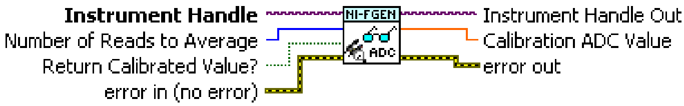
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ ENABLED` **value**: `VI_FALSE`

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

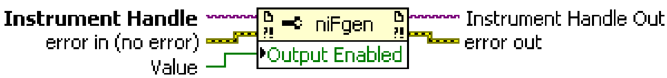
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

Note Do not insert any additional settling time between steps 12 and 13.

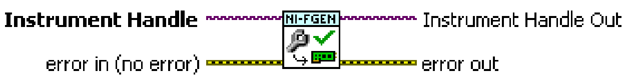
13. Measure the analog output voltage with the onboard calibration ADC by calling the niFgen Read CAL ADC VI.

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 27.

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

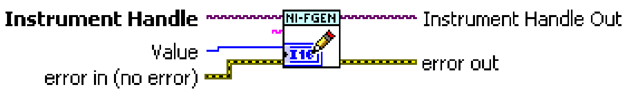
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ENABLED` **value**: `VI_TRUE`

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

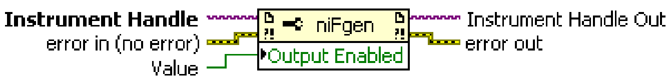
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Commit` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

16. Wait 500 ms for the output to settle.

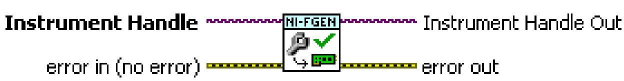
17. Use the DMM to measure the NI 5450 differential voltage output. This measurement, divided by 2, is external measurement 0, which is used in step 27.
18. Configure the DMM according to Configuration 2 in Table 25.
19. Set the main DAC value by calling the niFgen Write Binary 16 Analog Static Value 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`

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

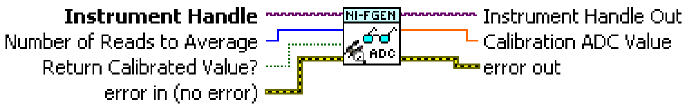
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_SetAttribute ViBoolean` using the following parameters: **vi**: The session handle returned from `niFgen_InitExtCal` **channelName**: `NULL` **attributeId**: `NIFGEN_ATTR_OUTPUT_ ENABLED` **value**: `VI_FALSE`

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

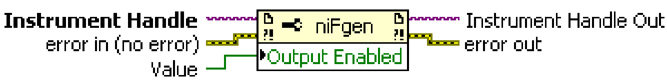
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_Initialize FlatnessCalibration` using the following parameter: **vi**: The session handle returned from `niFgen_InitExtCal`

Note Do not insert any additional settling time between steps 21 and 22.

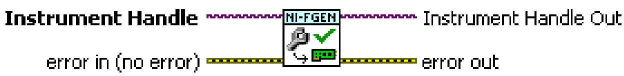
22. Measure the analog output voltage with the onboard calibration ADC by calling the niFgen Read CAL ADC VI.

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 27.

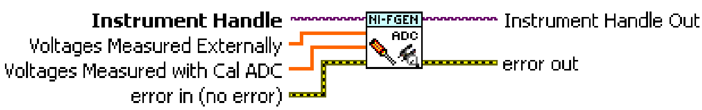
23. Enable the analog output by calling the niFgen Property Node and selecting **Output»Output Enabled**.

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`

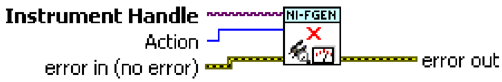
24. Commit the attribute values to the device by calling the niFgen Commit VI.

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

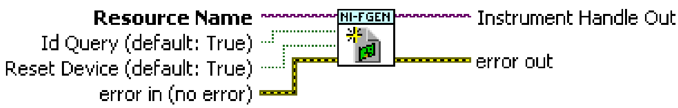
25. Wait 500 ms for the output to settle.
26. Use the DMM to measure the NI 5450 voltage output. This measurement, divided by 2, is external measurement 1, which is used in step 27.
27. Call the niFgen Cal Adjust Cal ADC VI.

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.

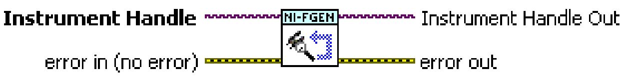
28. Close the instrument driver session and save the calibration date and temperature by calling the niFgen Close Ext Cal VI.

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.

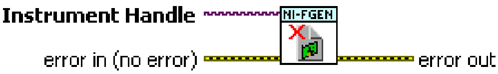
29. Open a session by calling the niFgen Initialize VI.

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

30. 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`

31. 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 DC ADC reference of the NI 5450. Repeat the *Verification* section to reverify the performance of the NI 5450 after all adjustments have been completed.

Adjusting the Frequency Response (Flatness)

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

Note Allow the NI 5450 and support equipment to warm up for a minimum of 30 minutes prior to performing an adjustment.

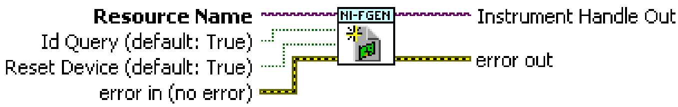
1. Connect the power meters to the CH 0 output terminals of the NI 5450 as shown in Figure 8.

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

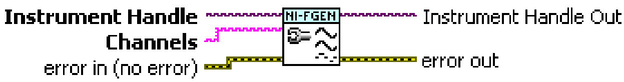
2. Configure the power meter as follows:
   - Multichannel
   - Average: 128
   - Measure watts
   - Channel 1 power sensor connected to the NI 5450(+)
   - Channel 2 power sensor connected to the NI 5450(–)
   - High accuracy

Note Allow 10 seconds for the power meter to stabilize before recording each reading.

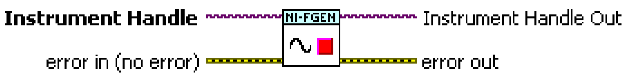
3. Open a session by calling the niFgen Initialize VI.

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

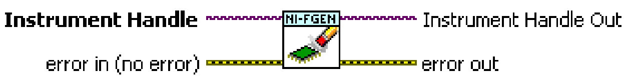
4. Prepare the channel for waveform generation by calling the niFgen Configure Channels VI.

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

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_GAIN` **value**: `0.5`

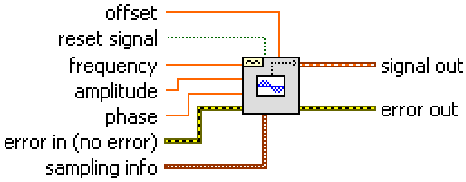
8. Set the sample rate by calling the niFgen Property Node and selecting **Clocks»Sample Clock»Rate**.

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`

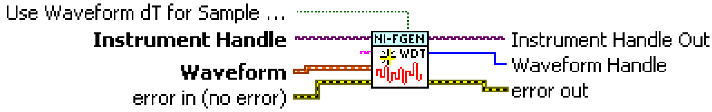
9. Set the flatness correction factor by calling the niFgen Property Node and selecting **Output»Filters»Flatness Correction Enabled.**

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`

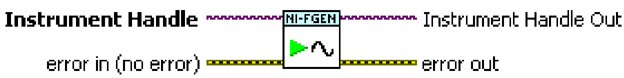
10. If you use C function calls, generate a sine wave. If you use LabVIEW, configure a waveform by calling the LabVIEW Sine Waveform VI with the following inputs:

LabVIEW Block Diagram

• **frequency**: The *Frequency* value in Table 26 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 26 for the current iteration.

11. 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 10. **waveformSize**: Value from Table 26. **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.

12. 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`

13. Record the readings from the power meters.
14. Repeat steps 5 through 13 for each frequency listed in Table 26.

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

15. Convert the power measurements from watts to volts by taking the square root.
16. Add the positive terminal voltage and the negative terminal voltage measurements for each frequency in Table 26 to obtain the differential voltage result.
17. Remove the DAC sinc response by dividing each differential voltage result by $\sin(x)/x$.

    where:

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

18. 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.

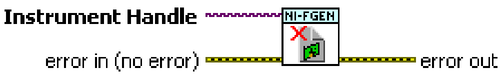
Table 26. Frequencies and Samples for Adjusting Sine Wave Flatness Correction

Frequencies	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

Table 26. Frequencies and Samples for Adjusting Sine Wave Flatness Correction (Continued)

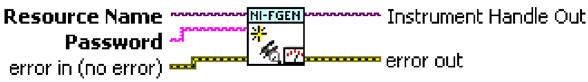
Frequencies	Samples
110 MHz	1,200,000
120 MHz	100,000
130 MHz	400,000
140 MHz	200,000
150 MHz	80,000
160 MHz	50,000
170 MHz	800,000
180 MHz	800,000
190 MHz	400,000

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

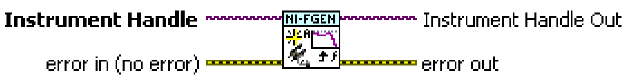
LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_close` using the following parameter: **vi**: The session handle returned from `niFgen_init`

20. Connect the power meters to the CH 1 output terminals of the NI 5450 as shown in Figure 9.
21. Repeat steps 3 through 19 for CH 1.

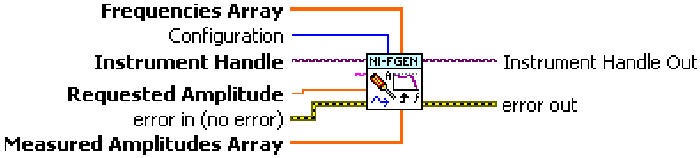
22. Open an NI-FGEN external calibration session by calling the niFgen Init Ext Cal VI.

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.

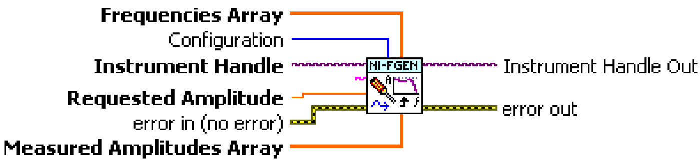
23. Initialize flatness calibration by calling the niFgen Initialize Flatness Calibration VI.

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

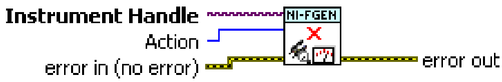
24. Adjust the onboard calibration constants by calling the niFgen Cal Adjust Flatness VI.

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CalAdjust Flatness` 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 26, including the 50 kHz Reference. **measuredAmplitudesArray**: An array of the amplitudes calculated in step 18 for CH 0.

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

LabVIEW Block Diagram	C/C++ Function Call
	Call `niFgen_CalAdjust Flatness` 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 26, including the 50 kHz Reference. **measuredAmplitudesArray**: An array of the amplitudes calculated in step 18 for CH 1.

26. 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 frequency response (flatness) of the NI 5450. Repeat the *Verification* section to reverify the performance of the NI 5450 after adjustments.

Verification Records

This section includes the verification limits for the following specifications:

- DC Voltage Absolute Accuracy
- DC Voltage Amplitude Channel-to-Channel Relative Accuracy
- DC Voltage Differential Offset
- DC Voltage Common Mode Offset
- AC Voltage Amplitude Absolute Accuracy
- AC Amplitude Channel-to-Channel Relative Accuracy
- Channel-to-Channel Timing Alignment Accuracy
- AC Voltage Amplitude Frequency Response (Flatness) Accuracy
- Average Noise Density
- Internal Reference Clock Frequency Accuracy

Compare these limits to the results you obtain in the *Verification* section.

Note Limits in the following tables are based upon the March 2009 edition of the *NI 5450 Specifications*. Refer to the most recent NI 5450 specifications online at `ni.com/manuals`. If a more recent edition of the specifications is available, recalculate the limits based upon the latest specifications.

Note 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 in 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, but it is not a replacement for the user uncertainty analysis that takes in consideration user's conditions and practices.

Table 27. NI 5450 DC Voltage Amplitude Absolute Accuracy Verification Limits

CH	Range	Output	Negative As Found Test Limit	Negative After Adjustment Test Limit	Measured Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
0	2 V	+0.1 V	–0.004	–0.0018		+0.004	+0.0018	
0	2 V	+0.5 V	–0.004	–0.0018		+0.004	+0.0018	
0	2 V	+1.0 V	–0.004	–0.0018		+0.004	+0.0018	
0	2 V	–0.1 V	–0.004	–0.0018		+0.004	+0.0018	
0	2 V	–0.5 V	–0.004	–0.0018		+0.004	+0.0018	
0	2 V	–1.0 V	–0.004	–0.0018		+0.004	+0.0018	
1	2 V	+0.1 V	–0.004	–0.0018		+0.004	+0.0018	
1	2 V	+0.5 V	–0.004	–0.0018		+0.004	+0.0018	
1	2 V	+1.0 V	–0.004	–0.0018		+0.004	+0.0018	
1	2 V	–0.1 V	–0.004	–0.0018		+0.004	+0.0018	
1	2 V	–0.5 V	–0.004	–0.0018		+0.004	+0.0018	
1	2 V	–1.0 V	–0.004	–0.0018		+0.004	+0.0018	

Table 28. NI 5450 DC Voltage Differential Offset Accuracy Verification Limits

CH	Range	Output	Negative As Found Test Limit	Negative After Adjustment Test Limit	Measured Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
0	2 V	0.0 V	–1.000 0 mV	–0.7500 mV		+1.000 0 mV	+0.7500 mV	
1	2 V	0.0 V	–1.000 0 mV	–0.7500 mV		+1.000 0 mV	+0.7500 mV	

Table 29. DC Voltage Common Mode Offset Accuracy

CH	Range	Output	Negative As Found Test Limit	Negative After Adjustment Test Limit	Calculated Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
$\varepsilon_{V_{CMO}} = \frac{(V_{CMO(+)} + V_{CMO(-)})}{2}$								
0	2 V	0.0 V	–350.000 μV	–250.000 μV		+350.000 μV	+250.000 μV	
1	2 V	0.0 V	–350.000 μV	–250.000 μV		+350.000 μV	+250.000 μV	

Table 30. NI 5450 DC Voltage Amplitude Channel-to-Channel Relative Accuracy Verification Limits

CH	Range	Setting	Negative Test Limit	Calculated Value	Positive Test Limit	Measurement Uncertainty
$\varepsilon_{(0,\,1)} = V_{CH0} - V_{CH1}$						
0, 1	2 V	0.1 V	–1600 μV	$\varepsilon_{0,1}$=	+1600 μV	
0, 1	2 V	–0.1 V	–1600 μV	$\varepsilon_{0,1}$=	+1600 μV	
0, 1	2 V	0.5 V	–1600 μV	$\varepsilon_{0,1}$=	+1600 μV	
0, 1	2 V	–0.5 V	–1600 μV	$\varepsilon_{0,1}$=	+1600 μV	
0, 1	2 V	1.0 V	–1600 μV	$\varepsilon_{0,1}$=	+1600 μV	
0, 1	2 V	–1.0 V	–1600 μV	$\varepsilon_{0,1}$=	+1600 μV	

Table 31. NI 5450 AC Voltage Amplitude Absolute Accuracy Verification Limits

CH	Differential Range	Frequency	Negative As Found Test Limit	Negative After Adjustment Test Limit	Calculated Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
$\varepsilon = (\sqrt{2} \times V_{RMS} - 1) \times 100$								
0	2.0 V	50 kHz	–0.5%	–0.2%	ε =	+0.5%	+0.2%	
1	2.0 V	50 kHz	–0.5%	–0.2%	ε =	+0.5%	+0.2%	

Table 32. NI 5450 AC Amplitude Channel-to-Channel Relative Accuracy Verification Limits

CH	Differential Range	Frequency	Negative Test Limit	Calculated Value	Positive Test Limit	Measurement Uncertainty
$\varepsilon_{0,1} = 2 \times \sqrt{2} \times (V_{RMS_{CH0}} - V_{RMS_{CH1}})$						
0, 1	2.0 V	50 kHz	–4.0 mV	$\varepsilon_{0,1}$=	+4.0 mV	

Table 33. NI 5450 Channel-to-Channel Timing Alignment Accuracy Verification Limits

CH	Amplitude	Frequency	Negative Test Limit	Calculated Value	Positive Test Limit	Measurement Uncertainty
$t_{alignment} = \lvert t_{CH2} - t_{CH(1)} \rvert$						
0, 1	0 dBFS	10 MHz	0 ps	t_{align}=	35 ps	

Table 34. NI 5450 AC Voltage Amplitude Frequency Response (Flatness) Accuracy Verification Limits

CH	Amplitude	Frequency	Negative As Found Test Limit	Negative After Adjustment Test Limit	Calculated Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
$Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)} + W_{f(-)} + 2 \times \sqrt{W_{f(+)} \times W_{f(-)}}}{W_{Ref(+)} + W_{Ref(-)} + 2 \times \sqrt{W_{Ref(+)} \times W_{Ref(-)}}}\right]$								
0	0 dBFS	50 kHz	Reference $R_{(+)50}$ = _________ $R_{(-)50}$ = _________					
0	0 dBFS	10 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	100 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	1 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	10 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	20 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	30 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	40 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	50 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	60 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	0 dBFS	70 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	0 dBFS	80 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	0 dBFS	90 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	0 dBFS	100 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	0 dBFS	110 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	0 dBFS	120 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
1	0 dBFS	50 kHz	Reference $R_{(+)50}$ = _________ $R_{(-)50}$ = _________					

Table 34. NI 5450 AC Voltage Amplitude Frequency Response (Flatness) Accuracy Verification Limits (Continued)

CH	Amplitude	Frequency	Negative As Found Test Limit	Negative After Adjustment Test Limit	Calculated Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
1	0 dBFS	10 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	100 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	1 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	10 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	20 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	30 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	40 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	50 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	60 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	0 dBFS	70 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	0 dBFS	80 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	0 dBFS	90 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	0 dBFS	100 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	0 dBFS	110 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	0 dBFS	120 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
0	–20 dBFS	50 kHz	Reference $R_{(+)50}$ = __________ $R_{(-)50}$ = __________					
0	–20 dBFS	10 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	100 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	1 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	10 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	

Table 34. NI 5450 AC Voltage Amplitude Frequency Response (Flatness) Accuracy Verification Limits (Continued)

CH	Amplitude	Frequency	Negative As Found Test Limit	Negative After Adjustment Test Limit	Calculated Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
0	–20 dBFS	20 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	30 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	40 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	50 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	60 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch0(f)}$=	+0.24 dB	+0.22 dB	
0	–20 dBFS	70 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	–20 dBFS	80 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	–20 dBFS	90 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	–20 dBFS	100 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	–20 dBFS	110 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
0	–20 dBFS	120 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch0(f)}$=	+0.34 dB	+0.25 dB	
1	–20 dBFS	50 kHz	Reference $R_{(+)50}$ = __________ $R_{(–)50}$ = __________					
1	–20 dBFS	10 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	100 kHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	1 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	10 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	20 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	30 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	40 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	50 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	

Table 34. NI 5450 AC Voltage Amplitude Frequency Response (Flatness) Accuracy Verification Limits (Continued)

CH	Amplitude	Frequency	Negative As Found Test Limit	Negative After Adjustment Test Limit	Calculated Value	Positive As Found Test Limit	Positive After Adjustment Test Limit	Measurement Uncertainty
1	–20 dBFS	60 MHz	–0.24 dB	–0.22 dB	$Flatness_{ch1(f)}$=	+0.24 dB	+0.22 dB	
1	–20 dBFS	70 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	–20 dBFS	80 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	–20 dBFS	90 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	–20 dBFS	100 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	–20 dBFS	110 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	
1	–20 dBFS	120 MHz	–0.34 dB	–0.25 dB	$Flatness_{ch1(f)}$=	+0.34 dB	+0.25 dB	

Table 35. NI 5450 Average Noise Density Verification Limits

CH	Amplitude	Frequency	Measured Value	Positive Test Limit	Measurement Uncertainty
$AVG\_ND = 20 \times \log_{10}\left(\frac{\sum_{i=1}^{n} 10^{\left\langle\frac{NoiseDensity(i)}{20}\right\rangle}}{n}\right)$					
0	–40 dBFS	1 MHz	*NoiseDensity* (10 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (20 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (30 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (40 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (50 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (60 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (70 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (80 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (90 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (100 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (110 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (120 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (130 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (140 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (150 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (160 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (170 MHz)=____________dBm/Hz	–160 dBm/Hz	

Table 35. NI 5450 Average Noise Density Verification Limits (Continued)

CH	Amplitude	Frequency	Measured Value	Positive Test Limit	Measurement Uncertainty
0	–40 dBFS	1 MHz	*NoiseDensity* (180 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (190 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	*NoiseDensity* (200 MHz)=____________dBm/Hz	–160 dBm/Hz	
0	–40 dBFS	1 MHz	AVG_ND_{CH0}=______________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (10 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (20 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (30 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (40 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (50 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (60 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (70 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (80 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (90 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (100 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (110 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (120 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (130 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (140 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (150 MHz)=____________dBm/Hz	–160 dBm/Hz	

Table 35. NI 5450 Average Noise Density Verification Limits (Continued)

CH	Amplitude	Frequency	Measured Value	Positive Test Limit	Measurement Uncertainty
1	–40 dBFS	1 MHz	*NoiseDensity* (160 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (170 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (180 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (190 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	*NoiseDensity* (200 MHz)=____________dBm/Hz	–160 dBm/Hz	
1	–40 dBFS	1 MHz	AVG_ND_{CH1}=____________dBm/Hz	–160 dBm/Hz	

Table 36. NI 5450 Internal Reference Clock Frequency Accuracy Verification Limits

CH	Amplitude	Frequency	Negative As Found Test Limit	Calculated Value	Positive Test Limit	Measurement Uncertainty
$\varepsilon = \frac{f_{meas} - 10M}{10\ M} \times 100$						
0	0 dBFS	10 MHz	–0.01%	ε=	+0.01%	

Optional Verification Limits

This section includes the verification limits for the following specifications:

- Channel-to-Channel Frequency Response (Flatness) Matching Accuracy
- Analog Bandwidth
- Spurious Free Dynamic Range (SFDR) with Harmonics Accuracy
- Spurious Free Dynamic Range without Harmonics Accuracy
- Total Harmonic Distortion (THD)
- Intermodulation Distortion (IMD_3)
- Rise/Fall Time
- Phase Noise Density
- Jitter

Compare these limits to the results you obtain in the *Verification* section.

Table 37. NI 5450 Channel-to-Channel Frequency Response (Flatness) Matching Accuracy Verification Limits

Amplitude	Frequency	Negative Test Limit, Typical	Calculated Value (dB)	Positive Test Limit, Typical
$\varepsilon_{(CH0-CH1)} = Flatness_{CH0(f)} - Flatness_{CH1(f)}$				
0 dBFS	10 kHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	100 kHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	1 MHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	10 MHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	20 MHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	30 MHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	40 MHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	50 MHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	60 MHz	–0.03 dB	$\varepsilon_{(CH0-CH1)}=$	+0.03 dB
0 dBFS	70 MHz	–0.04 dB	$\varepsilon_{(CH0-CH1)}=$	+0.04 dB
0 dBFS	80 MHz	–0.04 dB	$\varepsilon_{(CH0-CH1)}=$	+0.04 dB
0 dBFS	90 MHz	–0.04 dB	$\varepsilon_{(CH0-CH1)}=$	+0.04 dB
0 dBFS	100 MHz	–0.04 dB	$\varepsilon_{(CH0-CH1)}=$	+0.04 dB

Table 37. NI 5450 Channel-to-Channel Frequency Response (Flatness) Matching Accuracy Verification Limits

Amplitude	Frequency	Negative Test Limit, Typical	Calculated Value (dB)	Positive Test Limit, Typical
0 dBFS	110 MHz	–0.04 dB	$\varepsilon_{(CH0-CH1)}$=	+0.04 dB
0 dBFS	120 MHz	–0.04 dB	$\varepsilon_{(CH0-CH1)}$=	+0.04 dB

Table 38. NI 5450 Analog Bandwidth Verification Limits

CH	Amplitude	Frequency	Calculate Value (dB)	Test Limit, Typical
$Flatness_{Ref} = 10 \times \log\left[\frac{W_{f(+)} + W_{f(-)} + 2 \times \sqrt{W_{f(+)} \times W_{f(-)}}}{W_{Ref(+)} + W_{Ref(-)} + 2 \times \sqrt{W_{Ref(+)} \times W_{Ref(-)}}}\right]$				
0	–1 dBFS	50 kHz	*Reference*=	—
0	–1 dBFS	130 MHz	*Flatness*=	≥ –2.25 dB
0	–1 dBFS	140 MHz	*Flatness*=	≥ –2.75 dB
0	–1 dBFS	145 MHz	*Flatness*=	≥ –3 dB
1	–1 dBFS	50 kHz	*Reference*=	—
1	–1 dBFS	130 MHz	*Flatness*=	≥ –2.25 dB
1	–1 dBFS	140 MHz	*Flatness*=	≥ –2.75 dB
1	–1 dBFS	145 MHz	*Flatness*=	≥ –3 dB

Table 39. NI 5450 Spurious Free Dynamic Range with Harmonics Accuracy Verification Limits

CH	Amplitude	Frequency	Calculated Value (dB)	Test Limit, Typical
$SFDR_{With\ Harmonics}$ = Ampl(carrier)–Ampl(LargeSpur)				
0	–1 dBFS	10 MHz	$SFDR_{With\ Harmonics}$=	≥70 dB
0	–1 dBFS	60 MHz	$SFDR_{With\ Harmonics}$=	≥68 dB
0	–1 dBFS	100 MHz	$SFDR_{With\ Harmonics}$=	≥62 dB
0	–1 dBFS	120 MHz	$SFDR_{With\ Harmonics}$=	≥62 dB
0	–1 dBFS	160 MHz	$SFDR_{With\ Harmonics}$=	≥62 dB
1	–1 dBFS	10 MHz	$SFDR_{With\ Harmonics}$=	≥70 dB

Table 39. NI 5450 Spurious Free Dynamic Range with Harmonics Accuracy Verification Limits (Continued)

CH	Amplitude	Frequency	Calculated Value (dB)	Test Limit, Typical
1	–1 dBFS	60 MHz	$SFDR_{With\ Harmonics}$=	≥68 dB
1	–1 dBFS	100 MHz	$SFDR_{With\ Harmonics}$=	≥62 dB
1	–1 dBFS	120 MHz	$SFDR_{With\ Harmonics}$=	≥62 dB
1	–1 dBFS	160 MHz	$SFDR_{With\ Harmonics}$=	≥62 dB

Table 40. NI 5450 Spurious Free Dynamic Range without Harmonics Accuracy Verification Limits

CH	Amplitude	Frequency	Calculated Value (dB)	Test Limit, Typical
$SFDR_{Without\ Harmonics}$= Ampl(carrier) – Ampl(Non–Harmonic LargeSpur)				
0	–1 dBFS	10 MHz	$SFDR_{Without\ Harmonics}$=	≥70 dB
0	–1 dBFS	60 MHz	$SFDR_{Without\ Harmonics}$=	≥68 dB
0	–1 dBFS	100 MHz	$SFDR_{Without\ Harmonics}$=	≥64 dB
0	–1 dBFS	120 MHz	$SFDR_{Without\ Harmonics}$=	≥62 dB
0	–1 dBFS	160 MHz	$SFDR_{Without\ Harmonics}$=	≥62 dB
1	–1 dBFS	10 MHz	$SFDR_{Without\ Harmonics}$=	≥70 dB
1	–1 dBFS	60 MHz	$SFDR_{Without\ Harmonics}$=	≥68 dB
1	–1 dBFS	100 MHz	$SFDR_{Without\ Harmonics}$=	≥64 dB
1	–1 dBFS	120 MHz	$SFDR_{Without\ Harmonics}$=	≥62 dB
1	–1 dBFS	160 MHz	$SFDR_{Without\ Harmonics}$=	≥62 dB

Table 41. NI 5450 Total Harmonic Distortion (THD) Verification Limits

CH	Amplitude	Frequency	Measured Value (dBc)	Test Limit, Typical
0	–1 dBFS	10.1 MHz	THD =	≤–75 dBc
0	–1 dBFS	20.1 MHz	THD =	≤–70 dBc
0	–1 dBFS	40.1 MHz	THD =	≤–68 dBc
0	–1 dBFS	80.1 MHz	THD =	≤–68 dBc
0	–1 dBFS	100.1 MHz	THD =	≤–68 dBc

Table 41. NI 5450 Total Harmonic Distortion (THD) Verification Limits (Continued)

CH	Amplitude	Frequency	Measured Value (dBc)	Test Limit, Typical
0	–1 dBFS	120.1 MHz	THD =	≤–78 dBc
0	–1 dBFS	160.1 MHz	THD =	≤–83 dBc
1	–1 dBFS	10.1 MHz	THD =	≤–75 dBc
1	–1 dBFS	20.1 MHz	THD =	≤–70 dBc
1	–1 dBFS	40.1 MHz	THD =	≤–68 dBc
1	–1 dBFS	80.1 MHz	THD =	≤–68 dBc
1	–1 dBFS	100.1 MHz	THD =	≤–68 dBc
1	–1 dBFS	120.1 MHz	THD =	≤–78 dBc
1	–1 dBFS	160.1 MHz	THD =	≤–83 dBc

Table 42. NI 5450 Intermodulation Distortion (IMD_3) Verification Limits

CH	Amplitude	Frequency	Calculated Value (dBC)	Test Limit, Typical
			$Max(P_{\langle 2\times f_2 - f_1\rangle}, P_{\langle 2\times f_1 - f_2\rangle}) - Min(P_{f_1}, P_{f_2})$	
0	–7 dBFS	10 MHz	IMD_3=	≤–84 dBc
0	–7 dBFS	20 MHz	IMD_3=	≤–81 dBc
0	–7 dBFS	40 MHz	IMD_3=	≤–75 dBc
0	–7 dBFS	60 MHz	IMD_3=	≤–71 dBc
0	–7 dBFS	80 MHz	IMD_3=	≤–68 dBc
0	–7 dBFS	120 MHz	IMD_3=	≤–68 dBc
0	–7 dBFS	160 MHz	IMD_3=	≤–66 dBc
1	–7 dBFS	10 MHz	IMD_3=	≤–84 dBc
1	–7 dBFS	20 MHz	IMD_3=	≤–81 dBc
1	–7 dBFS	40 MHz	IMD_3=	≤–75 dBc
1	–7 dBFS	60 MHz	IMD_3=	≤–71 dBc
1	–7 dBFS	80 MHz	IMD_3=	≤–68 dBc

Table 42. NI 5450 Intermodulation Distortion (IMD_3) Verification Limits (Continued)

CH	Amplitude	Frequency	Calculated Value (dBC)	Test Limit, Typical
1	–7 dBFS	120 MHz	IMD_3 =	≤–68 dBc
1	–7 dBFS	160 MHz	IMD_3 =	≤–66 dBc

Table 43. NI 5450 Rise and Fall Time Verification Limits

CH	Amplitude	Frequency	Measured Value	Test Limit, Typical
0+	330 mV_{pk-pk}	33 MHz	Rise time =______ ns	≤3 ns
0+	330 mV_{pk-pk}	33 MHz	Fall time =______ ns	≤3 ns
0+	330 mV_{pk-pk}	33 MHz	Rising Edge Aberration =____%	≤7%
0+	330 mV_{pk-pk}	33 MHz	Falling Edge Aberration =____%	≤7%
0-	330 mV_{pk-pk}	33 MHz	Rise time =______ ns	≤3 ns
0-	330 mV_{pk-pk}	33 MHz	Fall time =______ ns	≤3 ns
0-	330 mV_{pk-pk}	33 MHz	Rising Edge Aberration =____%	≤7%
0-	330 mV_{pk-pk}	33 MHz	Falling Edge Aberration =____%	≤7%
1+	330 mV_{pk-pk}	33 MHz	Rise time =______ns	≤3 ns
1+	330 mV_{pk-pk}	33 MHz	Fall time =______ns	≤3 ns
1+	330 mV_{pk-pk}	33 MHz	Rising Edge Aberration =____%	≤7%
1+	330 mV_{pk-pk}	33 MHz	Falling Edge Aberration =____%	≤7%
1-	330 mV_{pk-pk}	33 MHz	Rise time =______ns	≤3 ns
1-	330 mV_{pk-pk}	33 MHz	Fall time =______ns	≤3 ns
1-	330 mV_{pk-pk}	33 MHz	Rising Edge Aberration =____%	≤7%
1-	330 mV_{pk-pk}	33 MHz	Falling Edge Aberration =____%	≤7%

Table 44. NI 5450 Phase Noise Density and Jitter Verification Limits

CH	Amplitude	Frequency	Measured Value	Test Limit, Typical
0	0 dBFS	10 MHz	PND $_{[100\ Hz]}$ =______dBc/Hz	≤–121 dBc/Hz
0	0 dBFS	10 MHz	PND $_{[1\ kHz]}$ =______dBc/Hz	≤–137 dBc/Hz
0	0 dBFS	10 MHz	PND $_{[10\ kHz]}$ =______dBc/Hz	≤–146 dBc/Hz
0	0 dBFS	10 MHz	PND $_{[100\ kHz]}$ =______dBc/Hz	≤–152 dBc/Hz
0	0 dBFS	10 MHz	PND $_{[1\ MHz]}$ =______dBc/Hz	≤–153 dBc/Hz
0	0 dBFS	10 MHz	Jitter $_{[100\ Hz–100\ kHz]}$ =____fs	≤350 fs
0	0 dBFS	100 MHz	PND $_{[100\ Hz]}$ =______dBc/Hz	≤–101 dBc/Hz
0	0 dBFS	100 MHz	PND $_{[1\ kHz]}$ =______dBc/Hz	≤–119 dBc/Hz
0	0 dBFS	100 MHz	PND $_{[10\ kHz]}$ =______dBc/Hz	≤–126 dBc/Hz
0	0 dBFS	100 MHz	PND $_{[100\ kHz]}$ =______dBc/Hz	≤–136 dBc/Hz
0	0 dBFS	100 MHz	PND $_{[1\ MHz]}$ =______dBc/Hz	≤–141 dBc/Hz
0	0 dBFS	100 MHz	Jitter $_{[100\ Hz–100\ kHz]}$ =____fs	≤350 fs
1	0 dBFS	10 MHz	PND $_{[100\ Hz]}$ =______dBc/Hz	≤–121 dBc/Hz
1	0 dBFS	10 MHz	PND $_{[1\ kHz]}$ =______dBc/Hz	≤–137 dBc/Hz
1	0 dBFS	10 MHz	PND $_{[10\ kHz]}$ =______dBc/Hz	≤–146 dBc/Hz
1	0 dBFS	10 MHz	PND $_{[100\ kHz]}$ =______dBc/Hz	≤–152 dBc/Hz
1	0 dBFS	10 MHz	PND $_{[1\ MHz]}$ =______dBc/Hz	≤–153 dBc/Hz
1	0 dBFS	10 MHz	Jitter $_{[100\ Hz–100\ kHz]}$ =____fs	≤350 fs
1	0 dBFS	100 MHz	PND $_{[100\ Hz]}$ =______dBc/Hz	≤–101 dBc/Hz
1	0 dBFS	100 MHz	PND $_{[1\ kHz]}$ =______dBc/Hz	≤–119 dBc/Hz
1	0 dBFS	100 MHz	PND $_{[10\ kHz]}$ =______dBc/Hz	≤–126 dBc/Hz
1	0 dBFS	100 MHz	PND $_{[100\ kHz]}$ =______dBc/Hz	≤–136 dBc/Hz
1	0 dBFS	100 MHz	PND $_{[1\ MHz]}$ =______dBc/Hz	≤–141 dBc/Hz
1	0 dBFS	100 MHz	Jitter $_{[100\ Hz–100\ kHz]}$ =____fs	≤350 fs

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