DEVICE SPECIFICATIONS

NI PXIe-5645R

Reconfigurable 6 GHz RF Vector Signal Transceiver with I/Q Interface

This document lists specifications for the NI PXIe-5645R (NI 5645R) RF vector signal transceiver (VST).

In this document, the term *vector signal analyzer* (VSA) refers to the RF input subsystem of the VST, and the term *vector signal generator* (VSG) refers to the RF output subsystem of the VST.

Specifications are warranted by design and under the following conditions, unless otherwise noted:

- 30 minutes warm-up time.
- Calibration cycle is maintained.
- Chassis fan speed is set to High. In addition, NI recommends using slot blockers and EMC filler panels in empty module slots to minimize temperature drift.
- Calibration IP is used properly during the creation of custom FPGA bitfiles.
- Calibration Interconnect cable remains connected between CAL IN and CAL OUT front panel connectors.

Caution Do not disconnect the cable that connects CAL IN to CAL OUT. Removing the cable from or tampering with the CAL IN or CAL OUT front panel connectors voids the product calibration and specifications are no longer warranted.

Unless otherwise noted, specifications assume the NI 5645R is configured in the following default mode of operation:

- Reference Clock source: Internal
- RF IN reference level: 0 dBm
- RF OUT power level: 0 dBm
- LO tuning mode: Fractional
- LO PLL loop bandwidth: Medium
- LO step size: 200 kHz
- LO frequency: 2.4 GHz
- LO source: Internal
- I/Q IN voltage range: 0.5 V_{pk-pk} differential
- I/Q IN common-mode voltage: 0 V
- I/Q OUT voltage range: 0.5 V_{pk-pk} differential

- I/Q OUT common-mode voltage: 0 V
- I/Q OUT load impedance: 50 Ω
- Digital equalization enabled for both RF and I/Q channels

Note Within the specifications, *self-calibration °C* refers to the recorded device temperature of the last successful self-calibration. You can read the self-calibration temperature from the device using the appropriate software functions.

Specifications describe the warranted, traceable product performance over ambient temperature ranges of 0 °C to 55 °C, unless otherwise noted.

Typical values describe useful product performance beyond specifications that are not covered by warranty and do not include guardbands for measurement uncertainty or drift. Typical values may not be verified on all units shipped from the factory. Unless otherwise noted, typical values cover the expected performance of units over ambient temperature ranges of 23 °C ± 5 °C with a 90% confidence level, based on measurements taken during development or production.

2σ specifications describe the 95th percentile values in which 95% of the cases are met with a 95% confidence for any ambient temperature of 23 °C ± 5 °C.

Nominal values (or supplemental information) describe additional information about the product that may be useful, including expected performance that is not covered under *Specifications* or *Typical* values. Nominal values are not covered by warranty.

Specifications are subject to change without notice. For the most recent device specifications, visit *ni.com/manuals*.

National Instruments RF devices are capable of producing and/or acquiring accurate signals within common Medical Implantable Communication System (MICS) frequency bands. NI RF devices are tested and verified in manufacturing for many measurements. For more information about RF device applications, visit *ni.com/niglobal* to contact a National Instruments branch office.

Caution The protection provided by this equipment may be impaired if it is used in a manner not described in the documentation.

Caution Do not disconnect the cable that connects CAL IN to CAL OUT. Removing the cable from or tampering with the CAL IN to CAL OUT front panel connectors voids the product calibration and specifications are no longer warranted.

To access NI 5645R documentation, navigate to **Start»All Programs»National Instruments» Vector Signal Transceivers**.

Contents

Frequency

The following characteristics are common to both RF IN and RF OUT ports.

Frequency range	65 MHz to 6 GHz
Bandwidth[1]	80 MHz
Tuning resolution[2]	<1 Hz
LO step size	
Fractional mode	Programmable step size, 200 kHz default
Integer mode	4 MHz, 5 MHz, 6 MHz, 12 MHz, 24 MHz

1 Digitally equalized RF input and RF output bandwidth. Bandwidth is restricted to 20 MHz for LO frequencies ≤ 109 MHz and restricted to 40 MHz for LO frequencies between 109 MHz and 375 MHz.
2 Tuning resolution combines LO step size capability and frequency shift DSP implemented on the FPGA.

Frequency Settling Time

Table 1. Maximum Frequency Settling Time

Settling Time	Maximum Time (ms)		
	Low Loop Bandwidth	**Medium Loop Bandwidth[3] (default)**	**High Loop Bandwidth**
$\leq 1 \times 10^{-6}$ of final frequency	1.1	0.95	0.38
$\leq 0.1 \times 10^{-6}$ of final frequency	1.2	1.05	0.4
The default medium loop bandwidth refers to a setting that adjusts PLL to balance tuning speed and phase noise, and it does not necessarily result in loop bandwidth between low and high. This specification includes only frequency settling and excludes any residual amplitude settling.			

Internal Frequency Reference

Initial adjustment accuracy	$\pm 200 \times 10^{-9}$
Temperature stability	$\pm 1 \times 10^{-6}$, maximum
Aging	$\pm 1 \times 10^{-6}$ per year, maximum
Accuracy	*Initial adjustment accuracy* ± *Aging* ± *Temperature stability*

Frequency Reference Input (REF IN)

Refer to the *REF IN* section.

Frequency Reference/Sample Clock Output (REF OUT)

Refer to the *REF OUT* section.

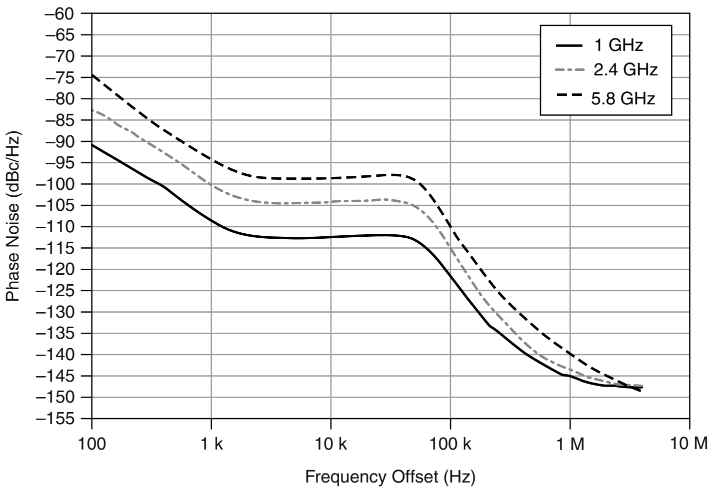
3 Medium loop bandwidth is available only in fractional mode.

Spectral Purity

Table 2. Single Sideband Phase Noise

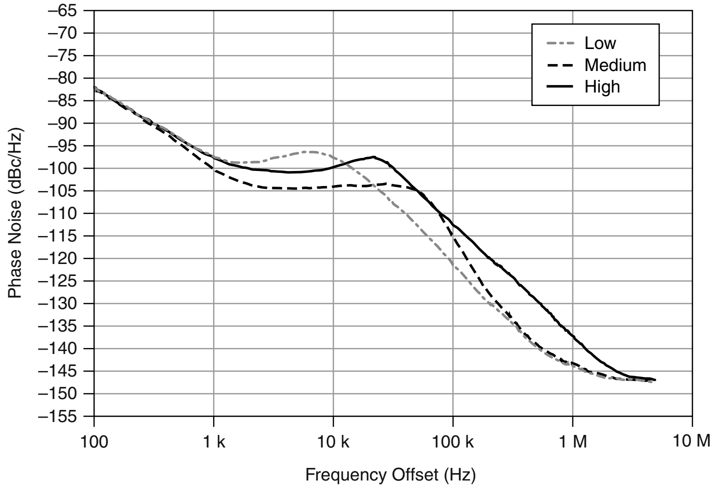
Frequency	Phase Noise (dBc/Hz), 20 kHz Offset (Single Sideband)		
	Low Loop Bandwidth	**Medium Loop Bandwidth**	**High Loop Bandwidth**
<3 GHz	-99	-99	-94
3 GHz to 4 GHz	-91	-93	-91
>4 GHz to 6 GHz	-93	-93	-87

Figure 1. Measured Phase Noise[4] at 1 GHz, 2.4 GHz, and 5.8 GHz



[4] Conditions: Measured port: LO Out; Reference Clock: internal; medium loop bandwidth.

Figure 2. Measured Phase Noise[5] at 2.4 GHz Versus Loop Bandwidth



RF Input

Amplitude Range

Amplitude range	Average noise level to +30 dBm (CW RMS)
RF reference level range/resolution	≥60 dB in 1 dB nominal steps

Amplitude Settling Time

<0.1 dB of final value[6]	125 µs, typical
<0.5 dB of final value[7], with LO retuned	300 µs

[5] Conditions: Measured port: LO Out; Reference Clock: internal.
[6] Constant LO frequency, constant RF input signal, varying input reference level.
[7] LO tuning across harmonic filter bands, constant RF input signal, varying input reference level.

Absolute Amplitude Accuracy

Table 3. VSA Absolute Amplitude Accuracy (dB)

Center Frequency	15 °C to 35 °C		0 °C to 55 °C	
	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
65 MHz to <375 MHz	—	±0.70	—	±0.75
	—	±0.65 (95th percentile, ≈ 2σ)	—	±0.65 (95th percentile, ≈ 2σ)
	±0.34, typical	±0.50, typical	±0.36, typical	±0.55, typical
375 MHz to <2 GHz	—	±0.65	—	±0.70
	—	±0.55 (95th percentile, ≈ 2σ)	—	±0.55 (95th percentile, ≈ 2σ)
	±0.17, typical	±0.35, typical	±0.22, typical	±0.40, typical
2 GHz to <4 GHz	—	±0.70	—	±0.75
	—	±0.55 (95th percentile, ≈ 2σ)	—	±0.60 (95th percentile, ≈ 2σ)
	±0.23, typical	±0.40, typical	±0.26, typical	±0.40, typical
4 GHz to 6 GHz	—	±0.90	—	±0.95
	—	±0.75 (95th percentile, ≈ 2σ)	—	±0.80 (95th percentile, ≈ 2σ)
	±0.30, typical	±0.55, typical	±0.33, typical	±0.55, typical

Conditions: reference level -30 dBm to +30 dBm; measured at 3.75 MHz offset from the configured center frequency; measurement performed after the NI 5645R has settled.

For reference levels <-30 dBm, absolute amplitude gain accuracy is ±0.6 dB, typical for frequencies ≤ 4 GHz, and ±0.8 dB, typical for frequencies > 4 GHz. Performance depends on signal-to-noise ratio.

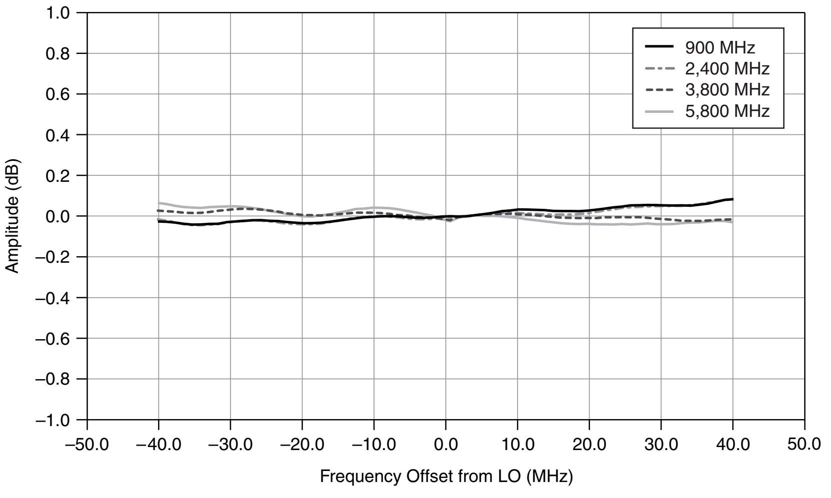
This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors.

Frequency Response

Table 4. VSA Frequency Response (dB) (Amplitude, Equalized)

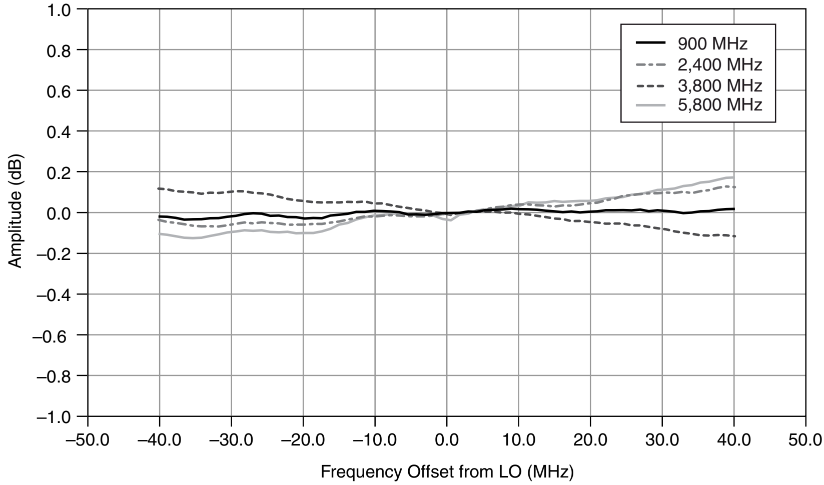
RF Input Frequency	Bandwidth	Self-Calibration °C ± 5 °C
≤109 MHz	20 MHz	±1.0, typical
>109 MHz to 375 MHz	20 MHz	±0.5
	40 MHz	±1.0, typical
>375 MHz to 6 GHz	80 MHz	±0.5
Conditions: Reference level -30 dBm to +30 dBm. This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors.		

Figure 3. Measured Frequency Response,[8] 0 dBm Reference Level, Equalized



8 Measurement performed after self-calibration.

Figure 4. Measured Frequency Response,[8] -30 dBm Reference Level, Equalized



Average Noise Density

Table 5. Average Noise Density (dBm/Hz)

Center Frequency	Average Noise Level	
	-50 dBm Reference Level	-10 dBm Reference Level
65 MHz to 4 GHz	-159	-145
	-161, typical	-148, typical
>4 GHz to 6 GHz	-156	-144
	-158, typical	-146, typical
Conditions: input terminated with a 50 Ω load; 50 averages; RMS average noise level normalized to a 1 Hz noise bandwidth. The -50 dBm reference level configuration has the inline preamplifier enabled, which represents the high sensitivity operation of the receive path.		

Spurious Responses

Nonharmonic Spurs

Table 6. Nonharmonic Spurs (dBc)

Frequency	<100 kHz Offset	≥100 kHz Offset	>1 MHz Offset
65 MHz to 3 GHz	<-55, typical	<-60	<-75
>3 GHz to 6 GHz	<-55, typical	<-55	<-70
Conditions: reference level ≥-30 dBm. Measured with a single tone, -1 dBr, where dBr is referenced to the configured RF reference level.			

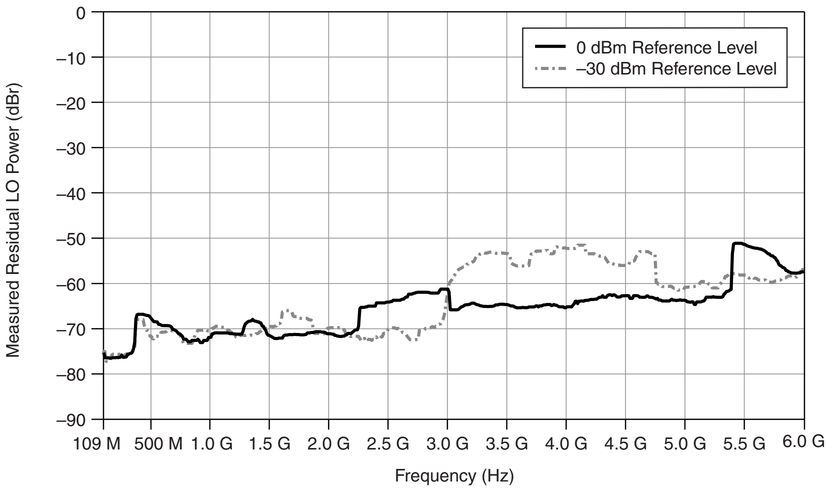
LO Residual Power

Table 7. VSA LO Residual Power (dBr[9])

Center Frequency	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
≤109 MHz	—	-62
	-70, typical	-67, typical
>109 MHz to 2 GHz	—	-58
	-65, typical	-61, typical
>2 GHz to 3 GHz	—	-55
	-60, typical	-58, typical
>3 GHz to 6 GHz	—	-45
	-56, typical	-48, typical
Conditions: Reference levels -30 dBm to +30 dBm; Measured at ADC. This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors. For optimal performance, NI recommends running self-calibration when the NI 5645R temperature drifts ± 5 °C from the temperature at the last self-calibration. For temperature changes >±5 °C from self-calibration, LO residual power is -35 dBr.		

[9] dBr is relative to the full scale of the configured RF reference level.

Figure 5. VSA LO Residual Power[10] , Typical



Residual Sideband Image

Table 8. VSA Residual Sideband Image, 80 MHz Bandwidth (dBc)

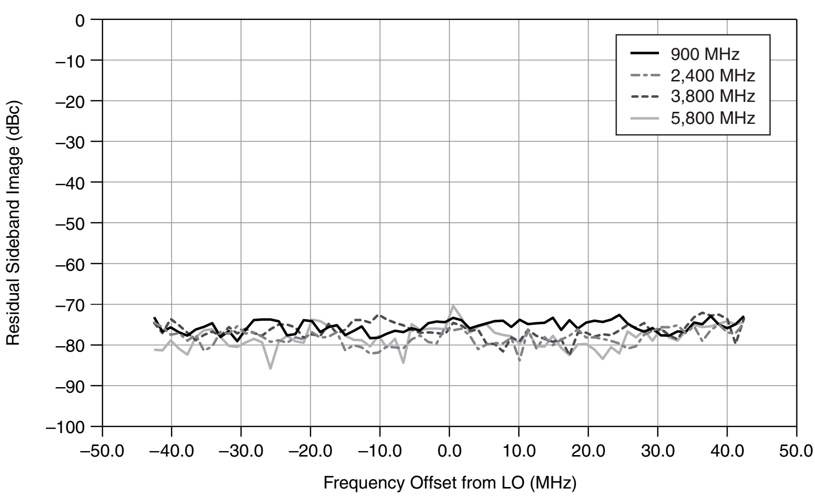
Center Frequency	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
≤109 MHz	—	-40
	-60, typical	-50, typical
>109 MHz to 500 MHz	—	-40
	-50, typical	-45, typical
>500 MHz to 3 GHz	—	-65
	-75, typical	-70, typical
>3 GHz to 5 GHz	—	-55
	-70, typical	-60, typical

10 Conditions: VSA frequency range 109 MHz to 6 GHz. Measurement performed after self-calibraton.

Table 8. VSA Residual Sideband Image, 80 MHz Bandwidth (dBc) (Continued)

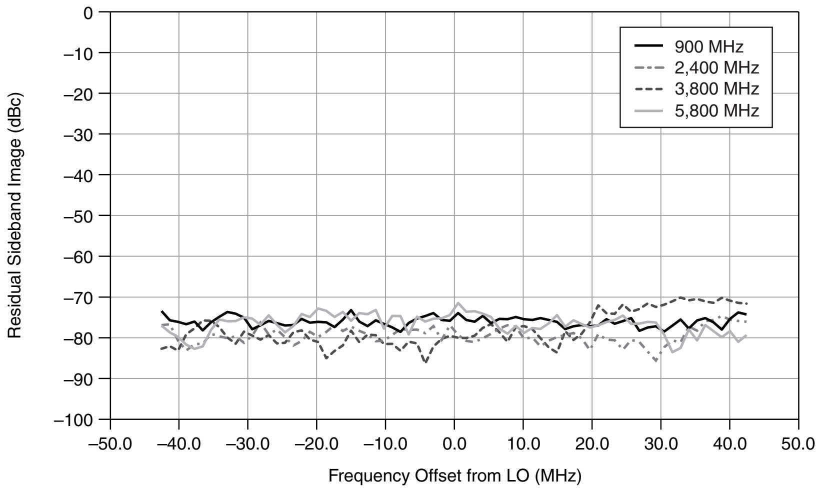
Center Frequency	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
>5 GHz to 6 GHz	—	-60
	-70, typical	-65, typical
Conditions: Reference levels -30 dBm to +30 dBm. This specification describes the maximum residual sideband image within an 80 MHz bandwidth at a given RF center frequency. Bandwidth is restricted to 20 MHz for LO frequencies ≤ 109 MHz. This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors. For optimal performance, NI recommends running self-calibration when the NI 5645R temperature drifts ± 5 °C from the temperature at the last self-calibration. For temperature changes >± 5 °C from self-calibration, residual image suppression is -40 dBc.		

Figure 6. VSA Residual Sideband Image,[11] 0 dBm Reference Level, Typical



[11] Measurement performed after self-calibration.

Figure 7. VSA Residual Sideband Image,[11] -30 dBm Reference Level, Typical



Third-Order Input Intermodulation

Table 9. Third-Order Input Intercept Point (IIP_3), -5 dBm Reference Level, Typical

Frequency Range	IIP_3 (dBm)
65 MHz to 1.5 GHz	19
>1.5 GHz to 6 GHz	20
Conditions: two -10 dBm tones, 700 kHz apart at RF IN; reference level: -5 dBm <4 GHz, -2 dBm reference level otherwise; nominal noise floor: -148 dBm/Hz for -5 dBm reference level, -145 dBm/Hz for -2 dBm reference level.	

Table 10. Third-Order Input Intercept Point (IIP_3), -20 dBm Reference Level, Typical

Frequency Range	IIP_3 (dBm)
65 MHz to 200 MHz	9
>200 MHz to 2 GHz	11
>2 GHz to 3.75 GHz	8
>3.75 GHz to 4.25 GHz	6
>4.25 GHz to 5 GHz	4

Table 10. Third-Order Input Intercept Point (IIP_3), -20 dBm Reference Level, Typical (Continued)

Frequency Range	IIP_3 (dBm)
>5 GHz to 6 GHz	1
Conditions: two -25 dBm tones, 700 kHz apart at RF IN; reference level: -20 dBm; nominal noise floor: -157 dBm/Hz.	

Second-Order Input Intermodulation

Table 11. Second-Order Input Intercept Point (IIP_2), -2 dBm Reference Level, Typical

Frequency Range	IIP_2 (dBm)
65 MHz to 1.5 GHz	67
>1.5 GHz to 4 GHz	58
>4 GHz to 6 GHz	52
Conditions: two -10 dBm tones, 700 kHz apart at RF IN; reference level: -2 dBm; nominal noise floor: -145 dBm/Hz.	

RF Output

Power Range

Table 12. Power Range

Output Type	Frequency	Power Range	
CW	<4 GHz	Noise floor to +10 dBm, average power[12]	Noise floor to +15 dBm, average power, nominal
	≥4 GHz	Noise floor to +7 dBm, average power[12]	Noise floor to +12 dBm, average power, nominal

[12] Higher output is uncalibrated and may be compressed.

Table 12. Power Range (Continued)

Output Type	Frequency	Power Range	
Modulated[13]	<4 GHz	Noise floor to +6 dBm, average power	—
	≥4 GHz	Noise floor to +3 dBm, average power	—

Output attenuator resolution	2 dB, nominal
Digital attenuation resolution[14]	0.1 dB or better

Related Information

Refer to the Considering Average Power and Crest Factor topic of the NI RF Vector Signal Transceivers Help for more information about modulated signal power.

Amplitude Settling Time

0.1 dB of final value[15]	50 µs
0.5 dB of final value[16], with LO retuned	300 µs

Output Power Level Accuracy

Table 13. Output Power Level Accuracy (dB)

Center Frequency	15 °C to 35 °C		0 °C to 55 °C	
	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
65 MHz to <109 MHz	—	±0.70	—	±0.90
	—	±0.55 (95th percentile, ≈ 2σ)	—	±0.65 (95th percentile, ≈ 2σ)
	±0.26, typical	±0.40, typical	±0.36, typical	±0.50, typical

13 Up to 12 dB crest factor, based on 3GPP LTE uplink requirements.
14 Average output power ≥ -100 dBm.
15 Constant LO frequency, varying RF output power range. Power levels ≤ 0 dBm. 175 µs for power levels > 0 dBm.
16 LO tuning across harmonic filter bands.

Table 13. Output Power Level Accuracy (dB) (Continued)

Center Frequency	15 °C to 35 °C		0 °C to 55 °C	
	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
109 MHz to <270 MHz[17]		±0.75		±0.90
		±0.60 (95th percentile; ≈ 2σ)		±0.70 (95th percentile; ≈ 2σ)
	±0.26, typical	±0.45, typical	±0.36, typical	±0.55, typical
270 MHz to <375 MHz	—	±0.70	—	±0.90
	—	±0.55 (95th percentile, ≈ 2σ)	—	±0.65 (95th percentile, ≈ 2σ)
	±0.26, typical	±0.40, typical	±0.36, typical	±0.50, typical
375 MHz to <2 GHz	—	±0.75	—	±0.90
	—	±0.55 (95th percentile, ≈ 2σ)	—	±0.65 (95th percentile, ≈ 2σ)
	±0.26, typical	±0.40, typical	±0.36, typical	±0.50, typical
2 GHz to <4 GHz	—	±0.75	—	±0.90
	—	±0.60 (95th percentile, ≈ 2σ)	—	±0.70 (95th percentile, ≈ 2σ)
	±0.26, typical	±0.40, typical	±0.36, typical	±0.50, typical

17 Harmonic suppression is reduced in this frequency range. As a result, offset errors may occur depending on whether you are using a true RMS device, such as a power meter.

Table 13. Output Power Level Accuracy (dB) (Continued)

Center Frequency	15 °C to 35 °C		0 °C to 55 °C	
	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
4 GHz to 6 GHz	—	±1.00	—	±1.15
	—	±0.80 (95th percentile, ≈ 2σ)	—	±0.90 (95th percentile, ≈ 2σ)
	±0.28, typical	±0.40, typical	±0.38, typical	±0.60, typical

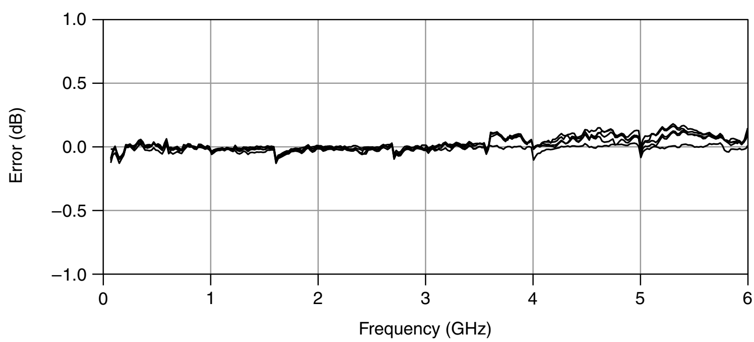
Conditions: CW average power -70 dBm to +10 dBm.

For power <-70 dBm, highly accurate generation can be achieved using digital attenuation, which relies on DAC linearity.

The absolute amplitude accuracy is measured at 3.75 MHz offset from the configured center frequency. The absolute amplitude accuracy measurements are made after the NI 5645R has settled.

This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors.

Figure 8. Relative Power Accuracy, -40 dBm to 10 dBm, 10 dB Steps, Typical

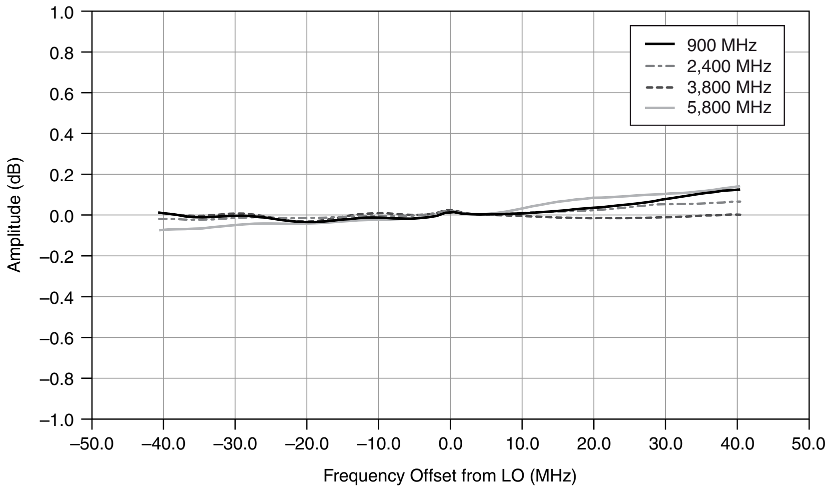


Frequency Response

Table 14. VSG Frequency Response (dB) (Amplitude, Equalized)

Output Frequency	Bandwidth	Self-Calibration °C ± 5 °C
≤109 MHz	20 MHz	±1.0, typical
>109 MHz to 375 MHz	20 MHz	±0.5
	40 MHz	±1.0, typical
>375 MHz to 6 GHz	80 MHz	±0.5
For this specification, frequency refers to the RF output frequency. This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors.		

Figure 9. VSG Measured Frequency Response[18]



18 Conditions: Output -10 dBm CW tone. Measurement performed after self-calibration.

Output Noise Density

Table 15. Average Output Noise Level (dBm/Hz)

Center Frequency	Power Setting		
	-30 dBm	0 dBm	10 dBm
65 MHz to 500 MHz	—	—	-136
	-168, typical	-150 , typical	-140, typical
>500 MHz to 2.5 GHz	-168, typical	-150	-141
>2.5 GHz to 3.5GHz	-168, typical	-149	-139
>3.5 GHz to 6 GHz	-165, typical	-147	-136
Conditions: Averages: 200 sweeps; baseband signal attenuation: -40 dB; noise measurement frequency offset: 4 MHz relative to output tone frequency.			

Spurious Responses

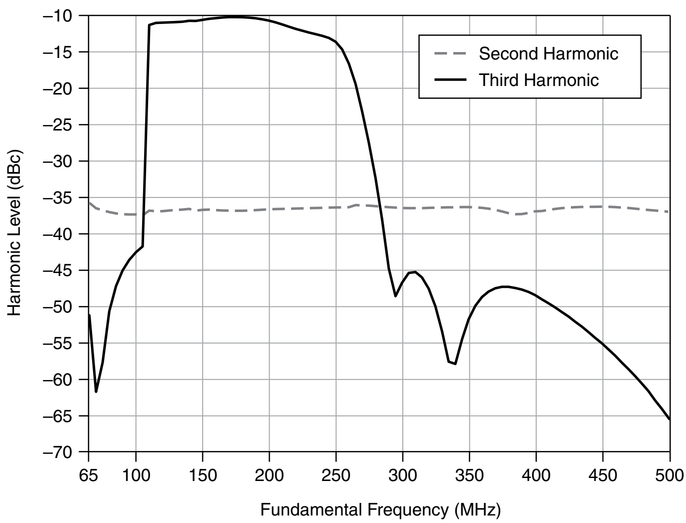
Harmonics

Table 16. Second Harmonic Level (dBc)

Fundamental Frequency	23 °C ± 5 °C	0 °C to 55 °C
65 MHz to 3.5 GHz	-27	-24.8
	-29.5, typical	-27.2, typical
>3.5 GHz to 4.5 GHz	-26.3	-24
	-28.9, typical	-26.6, typical
>4.5 GHz to 6 GHz	-28.9	-26.6
	-33.3, typical	-31, typical
Conditions: Measured using 1 MHz baseband signal -1 dBFS; fundamental signal measured at +6 dBm CW; second harmonic levels nominally <-30 dBc for fundamental output levels of ≤5 dBm.		

Note Higher order harmonic suppression is degraded in the range of 109 MHz to 270 MHz, and third harmonic performance is shown in the following figure. For frequencies outside the range of 109 MHz to 270 MHz, higher order harmonic distortion is equal to or better than the second harmonic level as specified in the previous table.

Figure 10. Harmonic Level[19], 65 MHz to 500 MHz, Measured



Nonharmonic Spurs

Table 17. Nonharmonic Spurs (dBc)

Frequency	<100 kHz Offset	≥100 kHz Offset	>1 MHz Offset
65 MHz to 3 GHz	<-55, typical	<-62	<-75
>3 GHz to 6 GHz	<-55, typical	<-57	<-70
Conditions: output full scale level ≥-30 dBm. Measured with a single tone at -1 dBFS.			

Third-Order Output Intermodulation

Table 18. Third-Order Output Intermodulation Distortion (IMD_3) (dBc), 0 dBm Tones

Fundamental Frequency	Baseband DAC: -2 dBFS	Baseband DAC: -6 dBFS
65 MHz to 1 GHz	-55, typical	-60, typical
>1 GHz to 3 GHz	-56, typical	-53, typical

19 Measured using 1 MHz baseband signal -1 dBFS; fundamental signal measured at +6 dBm CW.

Table 18. Third-Order Output Intermodulation Distortion (IMD_3) (dBc), 0 dBm Tones (Continued)

Fundamental Frequency	Baseband DAC: -2 dBFS	Baseband DAC: -6 dBFS
>3 GHz to 5 GHz	-49, typical	-50, typical
>5 GHz to 6 GHz	-44, typical	-45, typical
Conditions: two 0 dBm tones, 500 kHz apart at RF OUT. RF gain applied to achieve the desired output power per tone.		

Table 19. Third-Order Output Intermodulation Distortion (IMD_3) (dBc), -6 dBm Tones

Fundamental Frequency	Baseband DAC: -2 dBFS	Baseband DAC: -6 dBFS
65 MHz to 1.5 GHz	-50	-59
	-54, typical	-62, typical
>1.5 GHz to 3.5 GHz	-54	-59
	-57, typical	-62, typical
>3.5 GHz to 5 GHz	-50	-55
	-53, typical	-58, typical
>5 GHz to 6 GHz	-47	-51
	-50, typical	-54, typical
Conditions: two -6 dBm tones, 500 kHz apart at RF OUT. RF gain applied to achieve the desired output power per tone.		

Table 20. Third-Order Output Intermodulation Distortion (IMD_3) (dBc), -36 dBm Tones

Fundamental Frequency	Baseband DAC: -2 dBFS	Baseband DAC: -6 dBFS
65 MHz to 200 MHz	-52	-57
	-54, typical	-60, typical

Table 20. Third-Order Output Intermodulation Distortion (IMD_3) (dBc), -36 dBm Tones (Continued)

Fundamental Frequency	Baseband DAC: -2 dBFS	Baseband DAC: -6 dBFS
>200 MHz to 6 GHz	-52	-55
	-54, typical	-58, typical
Conditions: two -36 dBm tones, 500 kHz apart at RF OUT. RF gain applied to achieve the desired output power per tone.		

LO Residual Power

Table 21. VSG LO Residual Power (dBc)

Center Frequency	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
≤109 MHz	—	-50
	-60, typical	-55, typical
>109 MHz to 375 MHz	—	-45
	-65, typical	-50, typical
>375 MHz to 2 GHz	—	-55
	-67, typical	-60, typical
>2 GHz to 3 GHz	—	-50
	-60, typical	-53, typical
>3 GHz to 5 GHz	—	-55
	-65, typical	-58, typical

Table 21. VSG LO Residual Power (dBc) (Continued)

Center Frequency	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
>5 GHz to 6 GHz	—	-50
	-60, typical	-55, typical
Conditions: Configured power levels -50 dBm to +10 dBm. This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors. For optimal performance, NI recommends running self-calibration when the NI 5645R temperature drifts ± 5 °C from the temperature at the last self-calibration. For temperature changes >± 5 °C from self-calibration, LO residual power is -40 dBc.		

Figure 11. VSG LO Residual Power,[20] 109 MHz to 6 GHz, Typical

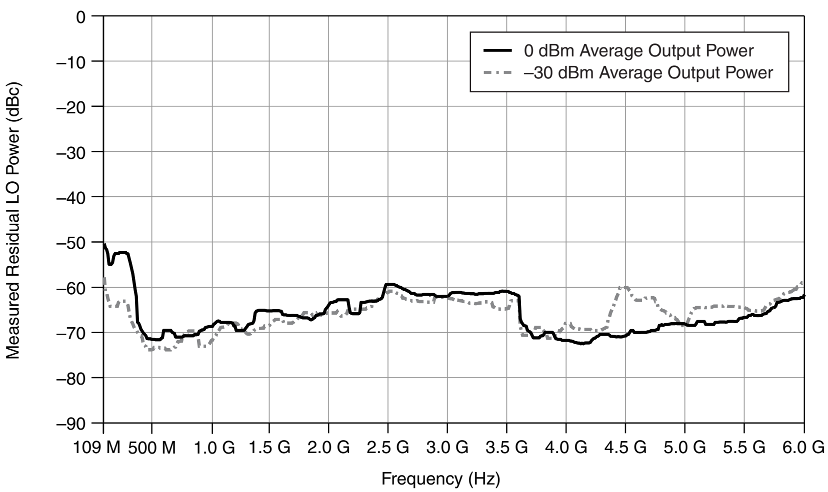


Table 22. VSG LO Residual Power (dBc), Low Power

Center Frequency	Self-Calibration °C ± 5 °C
≤109 MHz	—
	-49, typical

[20] Measurement performed after self-calibration.

Table 22. VSG LO Residual Power (dBc), Low Power (Continued)

Center Frequency	Self-Calibration °C ± 5 °C
>109 MHz to 375 MHz	-45
	-50, typical
>375 MHz to 2 GHz	-55
	-60, typical
>2 GHz to 3 GHz	-50
	-53, typical
>3 GHz to 4 GHz	-55
	-58, typical
>4 GHz to 5 GHz	—
	-40, typical
>5 GHz to 6 GHz	-43
	-45, typical
Conditions: Configured power levels < -50 dBm to -70 dBm. This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors. For optimal performance, NI recommends running self-calibration when the NI 5645R temperature drifts ± 5 °C from the temperature at the last self-calibration. For temperature changes >± 5 °C from self-calibration, LO residual power is -40 dBc.	

Residual Sideband Image

Table 23. VSG Residual Sideband Image (dBc), 80 MHz Bandwidth

Center Frequency	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
≤109 MHz	—	-40
	-55, typical	-45, typical
>109 MHz to 375 MHz	—	—
	-45, typical	-40, typical

Table 23. VSG Residual Sideband Image (dBc), 80 MHz Bandwidth (Continued)

Center Frequency	Self-Calibration °C ± 1 °C	Self-Calibration °C ± 5 °C
>375 MHz to 2 GHz	—	-60
	-70, typical	-65, typical
>2 GHz to 4 GHz	—	-50
	-65, typical	-55, typical
>4 GHz to 6 GHz	—	-40
	-70, typical	-50, typical

Conditions: Configured power levels -50 dBm to +10 dBm.

This specification describes the maximum residual sideband image within an 80 MHz bandwidth at a given RF center frequency. Bandwidth is restricted to 20 MHz for LO frequencies ≤ 109 MHz.

This specification is valid only when the module is operating within the specified ambient temperature range and within the specified range from the last self-calibration temperature, as measured with the onboard temperature sensors.

For optimal performance, NI recommends running self-calibration when the NI 5645R temperature drifts ± 5 °C from the temperature at the last self-calibration. For temperature changes >± 5 °C from self-calibration, residual image suppression is -40 dBc.

Figure 12. VSG Residual Sideband Image,[21] 0 dBm Average Output Power, Typical

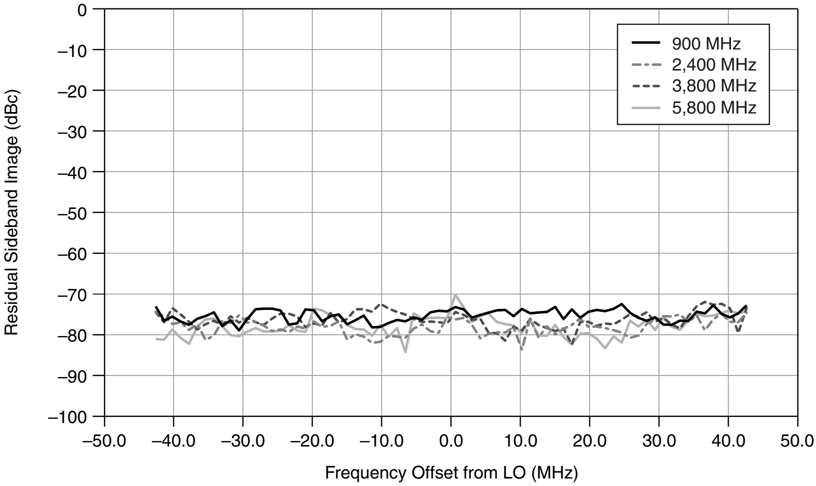
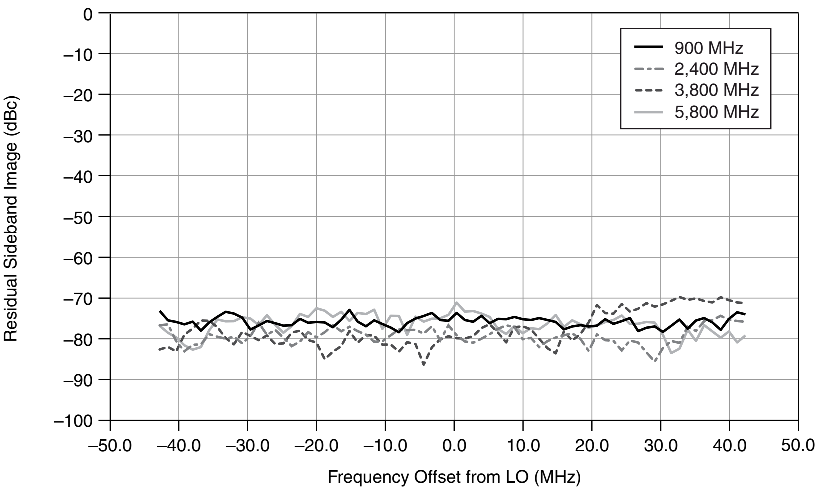


Figure 13. VSG Residual Sideband Image,[21] -30 dBm Average Output Power, Typical



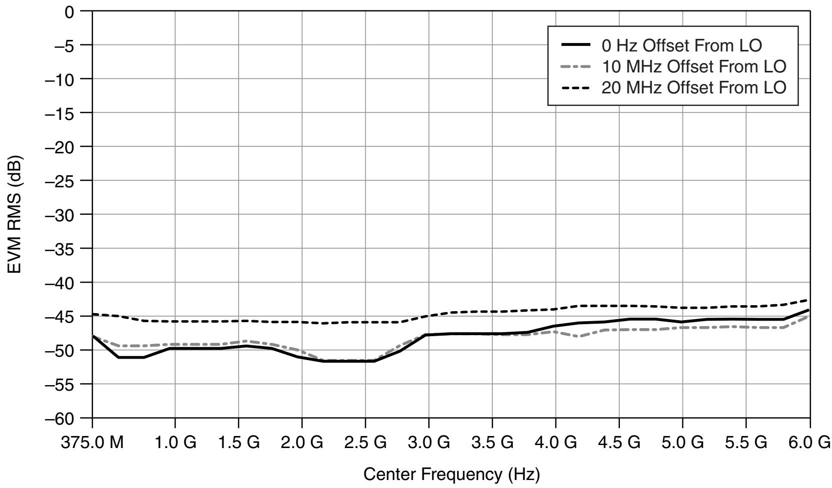
21 Measurement performed after self-calibration.

Error Vector Magnitude (EVM)

VSA EVM

20 MHz bandwidth 64-QAM EVM[22] 375 MHz to 6 GHz	-40 dB

Figure 14. VSA Error Vector Magnitude[23]



VSG EVM

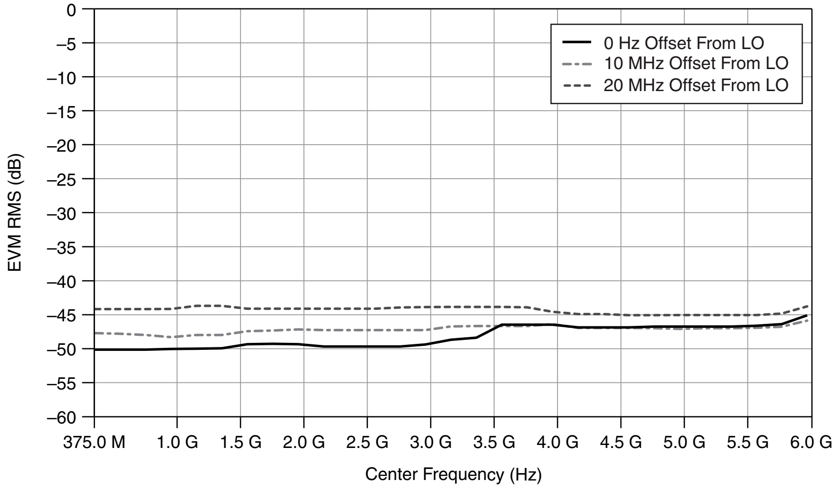
20 MHz bandwidth 64-QAM EVM[24] 375 MHz to 6 GHz	-40 dB

[22] Conditions: EVM signal: 20 MHz bandwidth; 64 QAM signal. Pulse-shape filtering: root-raised-cosine, alpha=0.25; NI 5645R reference level: -10 dBm; Reference Clock source: internal; record length: 300 µs. Generator: NI PXIe-5673; power (average): -14 dBm; Reference Clock source: internal.

[23] Conditions: 20 MHz bandwidth, 64 QAM; centered at LO frequency or offset digitally as listed.

[24] Conditions: EVM signal: 20 MHz bandwidth; 64 QAM signal. Pulse-shape filtering: root-raised cosine, alpha=0.25; NI 5645R peak output power: -10 dBm; Reference Clock source: internal. Measurement instrument: NI PXIe-5665; reference level: -10 dBm; Reference Clock source: internal; record length: 300 µs.

Figure 15. VSG Error Vector Magnitude[25]



I/Q Interface

Differential and Single-Ended Operation

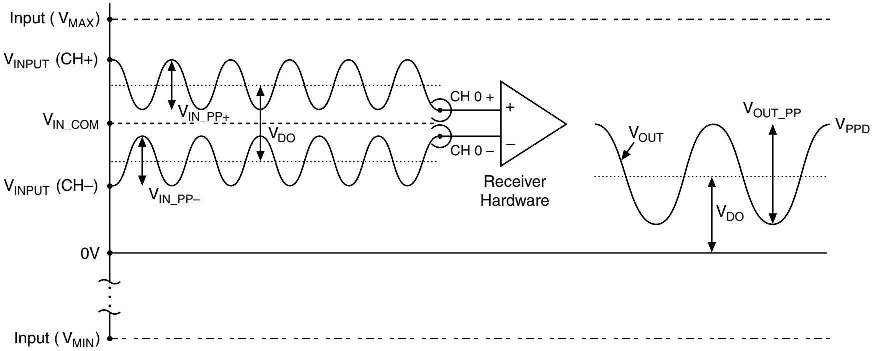
The I/Q inputs and outputs of the NI 5645R support both single-ended and differential operation. This section explains some of the fundamental analog signal processing that occurs in the first stages of the I/Q receiver.

A differential signal system has a positive component (V_{INPUT}(CH+)) and a negative component (V_{INPUT}(CH-)). The differential signal can have a common-mode offset (V_{IN_COM}) shared by both V_{INPUT}(CH+) and V_{INPUT}(CH-). The differential input signal is superimposed on the common-mode offset. The input circuitry rejects the input common-mode offset signal.

In a differential system, any noise present on both V_{INPUT}(CH+) and V_{INPUT}(CH-) gets rejected. Differential systems also double the dynamic range compared to a single-ended system with the same voltage swing. The following figure illustrates the key concepts of differential offset and common-mode offset associated with a differential system.

25 Conditions: 20 MHz bandwidth, 64 QAM; centered at LO frequency or offset digitally as listed.

Figure 16. Definition of Common-Mode Offset and Differential Offset



where

V_{IN_PP+} represents the peak-to-peak amplitude of the positive AC input signal

V_{IN_PP-} represents the peak-to-peak amplitude of the negative AC input signal

V_{DO} represents the differential offset voltage

V_{IN_COM} represents the common-mode offset voltage

V_{OUT_PP} represents the peak-to-peak amplitude of the output signal

In the previous figure, the input common-mode voltage is not present after the first stage of the receiver system. The signal remaining at the output of the receiver circuitry is the signal of interest.

Note The differential signal can have an offset between V_{INPUT}(CH+) and V_{INPUT}(CH-). This is known as the *differential offset* and is retained by the receiver circuitry.

In an I/Q analyzer, a differential offset can occur because of LO leakage or harmonics. In the case of I/Q generation, a differential offset can cause spurs and magnitude error.

In a phase-balanced differential system, the peak-to-peak amplitude of the positive AC input signal (V_{IN_PP+}) is equal to the peak-to-peak amplitude of the negative AC input signal (V_{IN_PP-}). The AC peak-to-peak amplitude of the output signal is the sum of V_{IN_PP+} and V_{IN_PP-}. A more general definition for the output voltage regardless of phase is the difference between V_{IN_PP+} and V_{IN_PP-} described by the following equation:

$$V_{OUT} = (V_{INPUT}(CH+)) - (V_{INPUT}(CH-))$$

The common-mode offset, which represents the rejected component common to both signals, is described by the following equation:

$$V_{IN\_COM} = [(V_{INPUT}(CH+)) + (V_{INPUT}(CH-))]/2$$

Related Information

Refer to the NI RF Vector Signal Transceivers Help for more information about differential and single-ended operation on the NI 5645R.

I/Q Input

Vertical Range

Maximum input voltage	
Maximum functional voltage	± 2.5 V, typical
Maximum input voltage[26] (damage)	±3 V
Common-mode range[27]	±2 V
Differential voltage range	
Analog	0.032 $V_{pk\text{-}pk}$ to 2 $V_{pk\text{-}pk}$
Digital	<0.032 $V_{pk\text{-}pk}$
Single-ended voltage range[28]	
Analog	0.032 $V_{pk\text{-}pk}$ to 2 $V_{pk\text{-}pk}$
Digital	<0.032 $V_{pk\text{-}pk}$
Analog gain step range	36 dB
Gain step resolution	1 dB, typical

Absolute DC Gain Accuracy

Table 24. I/Q Input Absolute DC Gain Error

Temperature Range	Absolute Gain Error
Within ±5 °C of 23 °C	±1.75%
	±1.10%, typical

[26] Common-mode voltage plus peak AC voltage cannot exceed the maximum input voltage of 2.5 V.
[27] Common-mode voltage plus peak AC voltage cannot exceed the maximum input voltage of 2.5 V. Valid for all differential levels.
[28] To use the I or Q channel in single-ended terminal configuration, connect the positive (+) terminal to the active signal and terminate the negative (-) terminal with a 50 Ω termination.

Table 24. I/Q Input Absolute DC Gain Error (Continued)

Temperature Range	Absolute Gain Error
Outside ±5 °C of 23°C	-0.033%/°C
	-0.027%/°C, typical
The accuracy of a measured DC signal using the 0.5 V differential input range is calculated using the following equations: Gain accuracy for temperature within ±5 °C of ambient 23 °C: ±(1.75% × 0.5 V) = ±8.75 mV Gain accuracy for a temperature at +20 °C above ambient 23 °C: ±8.75 mV - 0.033% × 15 °C × (0.5) = +6.28 mV/-11.23 mV	

Table 25. I/Q Input DC Offset Error (mV)

Temperature Range	I/Q Input DC Offset Error
23 °C ± 5 °C	±15
	±6, typical
0 °C to 55 °C	±20
	±10, typical

Absolute AC Gain Accuracy

Table 26. I/Q Input Absolute AC Gain Accuracy[29] (dB)

Input Range	23 °C ± 5 °C	0 °C to 55 °C
2 V_{pk-pk}	0.42	0.47
	0.1, typical	0.16, typical
0.5 V_{pk-pk}	0.41	0.47
	0.1, typical	0.16, typical
0.1 V_{pk-pk}	0.52	0.60
	0.1, typical	0.23, typical

[29] Configured for 0 V common-mode, differential. Measured CW at 500 kHz.

Complex Equalized Bandwidth

Complex I/Q equalized bandwidth[30]	80 MHz
Bandwidth (equalization enabled or disabled)	
Baseband	40 MHz
Complex baseband	80 MHz when used with an external I/Q modulator

Note To operate the device in complex baseband mode, configure each channel with identical ranges and termination. Complex baseband mode requires two input signals that are 90° out of phase.

Passband Flatness

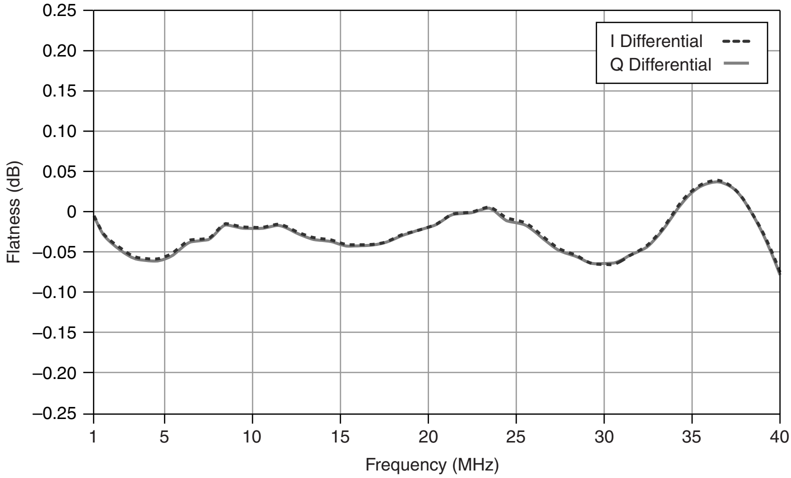
Table 27. I/Q Input Passband Flatness[31] (dB)

I or Q Bandwidth	23 °C ± 5 °C	0 °C to 55 °C
20 MHz	0.43	0.49
	0.15, typical	0.21, typical
40 MHz	0.52	0.58
	0.21, typical	0.27, typical

30 Complex equalized bandwidth is the combined bandwidth of I and Q channels. Valid only when using identical gain and termination settings for each I/Q channel.

31 Referenced to 500 kHz. Digital equalization enabled. Valid only when using identical gain and termination settings for each I/Q channel.

Figure 17. I/Q Input Passband Flatness[31]



Channel-to-Channel Gain Imbalance

Table 28. I/Q Input Gain Imbalance[32] (dB)

Complex Bandwidth	23 °C ± 5 °C	0 °C to 55 °C
40 MHz	± 0.025	± 0.06
	± 0.02, typical	± 0.04, typical
80 MHz	± 0.045	± 0.075
	± 0.03, typical	± 0.05, typical

Channel-to-Channel Phase Matching

Table 29. I/Q Input Phase Matching[33] (Degrees)

Complex Bandwidth	23 °C ± 5 °C	0 °C to 55 °C
40 MHz	± 0.10	± 0.3
	± 0.06, typical	± 0.16, typical

32 Digital equalization enabled. Valid only when using identical gain and termination settings for each I/Q channel.

33 Digital equalization enabled. Valid only when using identical gain and termination settings for each I/Q channel.

Table 29. I/Q Input Phase Matching[33] (Degrees) (Continued)

Complex Bandwidth	23 °C ± 5 °C	0 °C to 55 °C
80 MHz	± 0.16	± 0.5
	± 0.10, typical	± 0.35, typical

Image Suppression

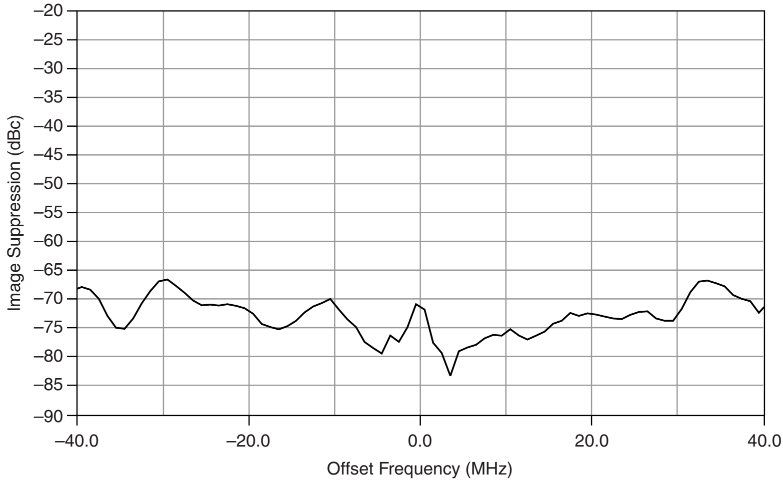
Table 30. I/Q Input Image Suppression[34] (dBc)

Complex Bandwidth	23 °C ± 5 °C
40 MHz	-60
	-63, typical
80 MHz	-57
	-60, typical
Image suppression is equivalent or better than specification at all frequency offsets within the specified bandwidth. For ambient temperatures from 0 °C to 55 °C, image suppression is -50 dBc, typical over 80 MHz of complex bandwidth. External calibration is recommended to optimize performance for a specific ambient temperature outside of 23 °C ± 5 °C.	

33 Digital equalization enabled. Valid only when using identical gain and termination settings for each I/Q channel.

34 Digital equalization enabled. Valid only when using identical gain and termination settings for each I/Q channel.

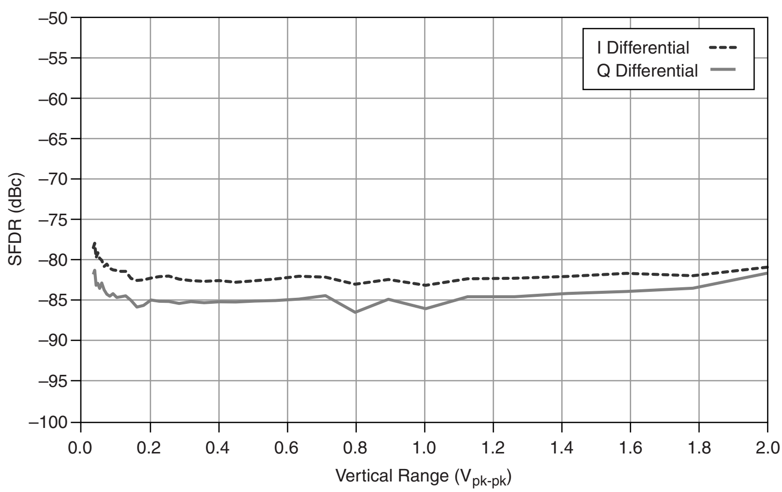
Figure 18. I/Q Input Image Suppression,[35] Nominal



Spectral Characteristics

Spurious Free Dynamic Range (SFDR)

Figure 19. Measured I/Q Input SFDR[36]



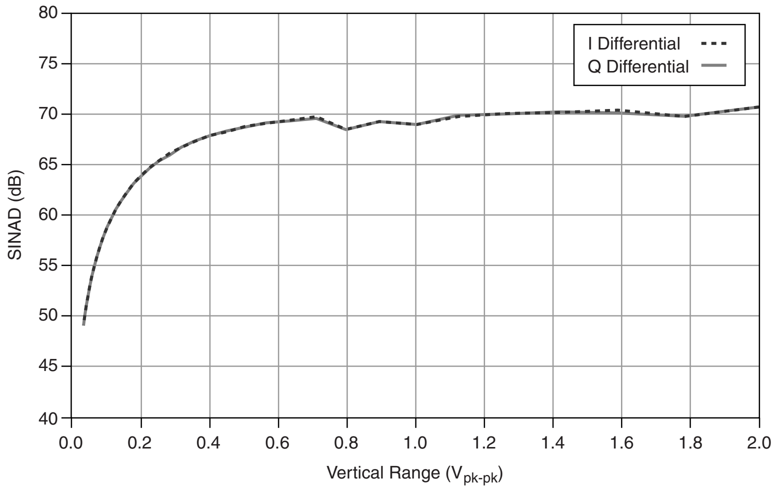
35 Measured at 23 °C. Valid only when using identical gain and termination settings for each I/Q channel.

36 Measured with a -1 dBFS tone at 9.9 MHz.

Signal to Noise and Distortion (SINAD)

I/Q input SINAD[37] (dB)	
23 °C ± 5 °C	69, typical
0 °C to 55 °C	67, typical

Figure 20. Measured I/Q Input SINAD[37]



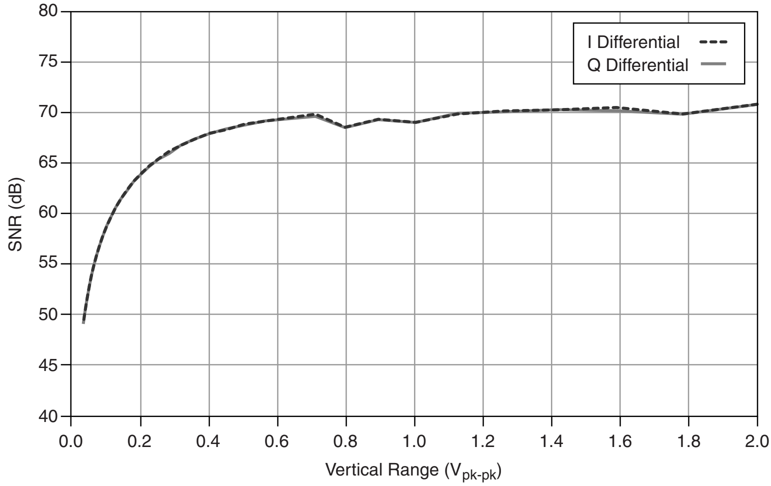
Signal-to-Noise Ratio (SNR)

I/Q input SNR[38] (dB)	
23 °C ± 5 °C	69, typical
0 °C to 55 °C	67, typical

37 Measured with a fixed -1 dBFS input signal at 9.9 MHz. Specification is valid within 20 MHz of bandwidth for I or Q.

38 Measured with a -1 dBFS input signal at 9.9 MHz. Specification is valid within 20 MHz of bandwidth for I or Q.

Figure 21. I/Q Input SNR[38]

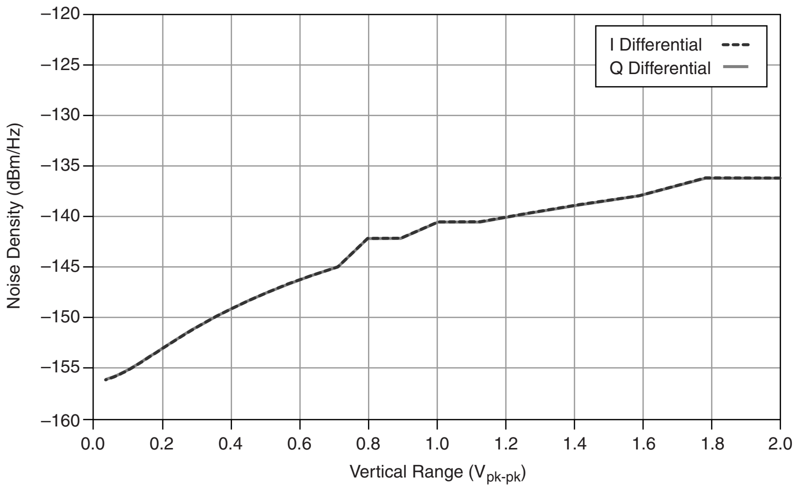


Average Noise Density

I/Q input average noise density[39] (dBm/Hz)	
23 °C ± 5 °C	-147, typical
0 °C to 55 °C	-146, typical

[39] Measured in the presence of a -40 dBFS signal.

Figure 22. Measured I/Q Input Noise Density[39]

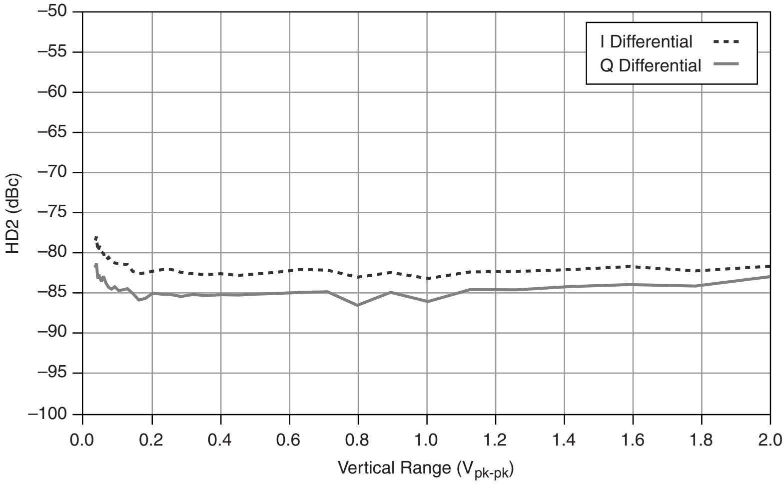


Harmonics

I/Q input second harmonic[40] (dBc)	
23 °C ± 5 °C	-76, typical
0 °C to 55 °C	-75, typical

40 Measured with a -1 dBFS input signal at 9.9 MHz.

Figure 23. Measured I/Q Input Second Harmonic[40]



I/Q input third harmonic[40] (dBc)	
23 °C ± 5 °C	-80, typical
0 °C to 55 °C	-79, typical

Figure 24. Measured I/Q Input Third Harmonic[40]

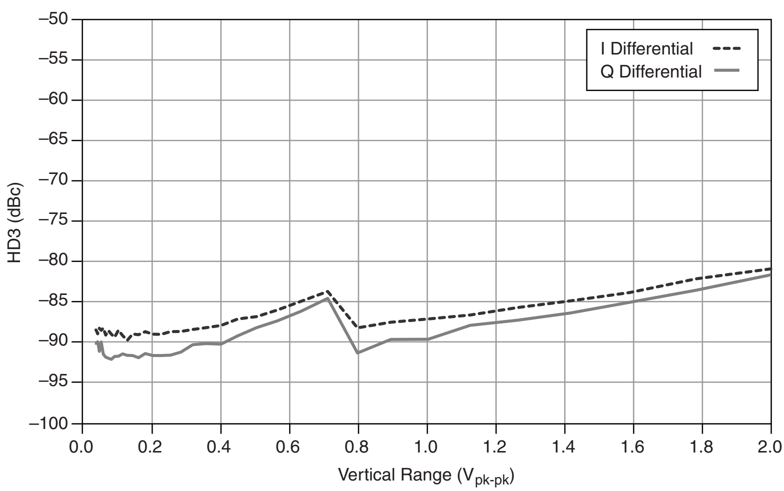
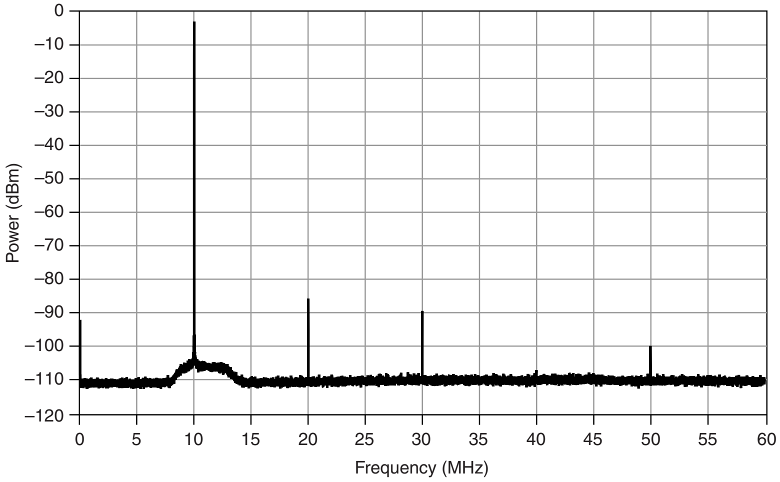


Figure 25. Measured I/Q Input Single Tone[41]



Third-Order Input Intermodulation

I/Q third-order input intermodulation[42] (IMD_3) (dBc)	
23 °C ± 5 °C	-80, typical
0 °C to 55 °C	-79, typical

41 Measured with 10 MHz bandpass filter to remove stimulus-related noise and distortion.
42 Measured with two-tone stimulus; each tone is -7 dBFS with a 200 kHz spacing; 9.9 MHz and 10.1 MHz tone frequencies.

Figure 26. Measured I/Q Input IMD_3[42]

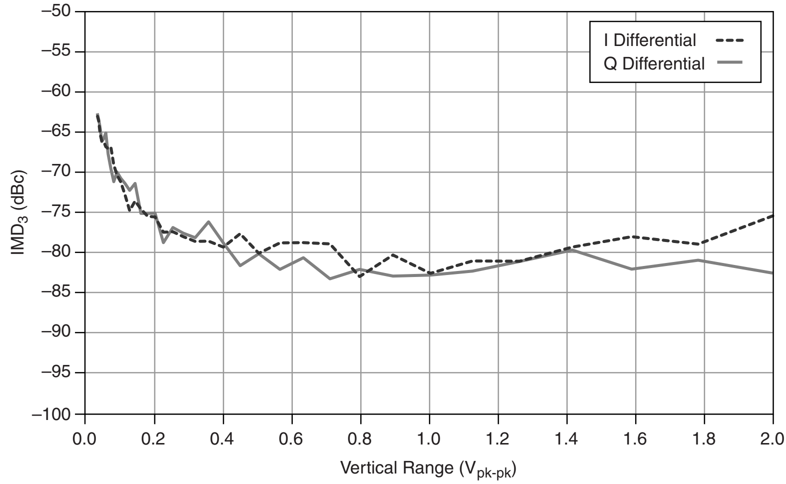
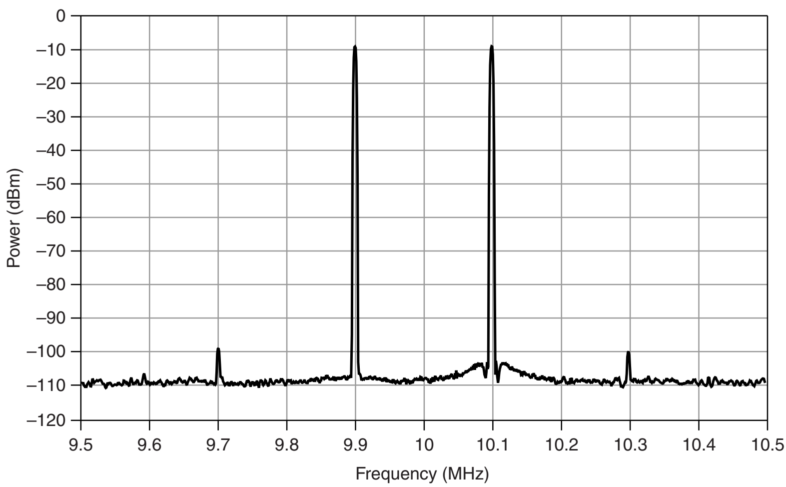


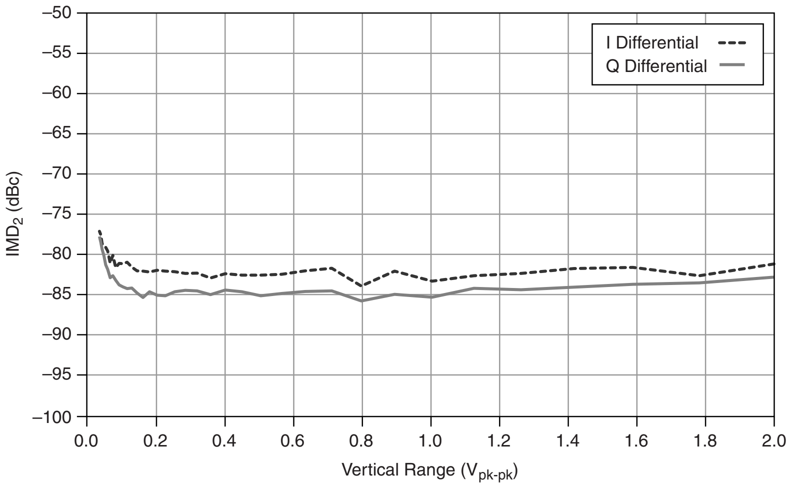
Figure 27. Measured I/Q Input Two-Tone Spectrum



Second-Order Input Intermodulation

I/Q second-order input intermodulation[43] (IMD_2) (dBc)	
23 °C ± 5 °C	-77, typical
0 °C to 55 °C	-75, typical

Figure 28. Measured I/Q Input IMD_2[43]



I/Q Output

Output Range[44]

Maximum output voltage	±2.5 V
Common-mode range[45]	±2 V
Differential voltage range	
Analog	$0.032V_{pk\text{-}pk}$ to $2\ V_{pk\text{-}pk}$
Digital	$< 0.032\ V_{pk\text{-}pk}$

43 Measured with two-tone stimulus; each tone is -7 dBFS with a 200 kHz spacing; 9.9 MHz and 10.1 MHz tone frequencies.
44 High-impedance load.
45 Valid for all differential levels.

Single-ended voltage range[46]	
Analog	0.016 $V_{pk\text{-}pk}$ to 1 $V_{pk\text{-}pk}$
Digital	< 0.016 $V_{pk\text{-}pk}$
Analog gain step range	36 dB
Gain step resolution	1 dB, typical

Absolute DC Gain Accuracy

Table 31. I/Q Output Absolute DC Gain Error[47]

Temperature Range	Absolute Gain Error
Within ±5 °C of 23 °C	±1.12%
	±0.62%, typical
Outside ±5 °C of 23°C	-0.055%/°C
	-0.045%/°C, typical
The accuracy of a measured DC signal using the 0.5 V differential output range is calculated using the following equations: Gain accuracy for temperature within ±5 °C of ambient 23 °C: ±(1.12% × 0.5 V) = ±5.6 mV Gain accuracy for a temperature at +20 °C above ambient 23 °C: ±5.6 mV - 0.055% × 15 °C × (0.5) = +1.5 mV/-9.8 mV	

Table 32. I/Q Output DC Offset Error[48] (mV)

Temperature Range	I/Q Output DC Offset Error
23 °C ± 5 °C	±3.6
	±2.5, typical
0 °C to 55 °C	±4.5
	±2.9, typical

46 To use the I or Q channel in single-ended terminal configuration, connect the positive (+) terminal to the active signal and terminate the negative (-) terminal with a 50 Ω termination.
47 Measured with a DMM. Measured with both output terminals terminated to ground through a high impedance.
48 High-impedance load.
49 Configured for 0 V common-mode, differential. Measured CW at 500 kHz.

Absolute AC Gain Accuracy

Table 33. I/Q Output Absolute AC Gain Accuracy[49] (dB)

Output Range	23 °C ± 5 °C	0 °C to 55 °C
1.0 $V_{pk\text{-}pk}$	0.48	0.53
	0.13, typical	0.19, typical
0.5 $V_{pk\text{-}pk}$	0.47	0.52
	0.13, typical	0.19, typical
0.1 $V_{pk\text{-}pk}$	0.57	0.64
	0.15, typical	0.22, typical

Complex Equalized Bandwidth

Complex I/Q equalized bandwidth[50]	80 MHz
Bandwidth (equalization enabled)	
Baseband	40 MHz
Complex baseband	80 MHz when used with an external I/Q modulator

Note To operate the device in complex baseband mode, configure each channel with identical ranges and termination. Complex baseband mode requires two input signals that are 90° out of phase.

Passband Flatness

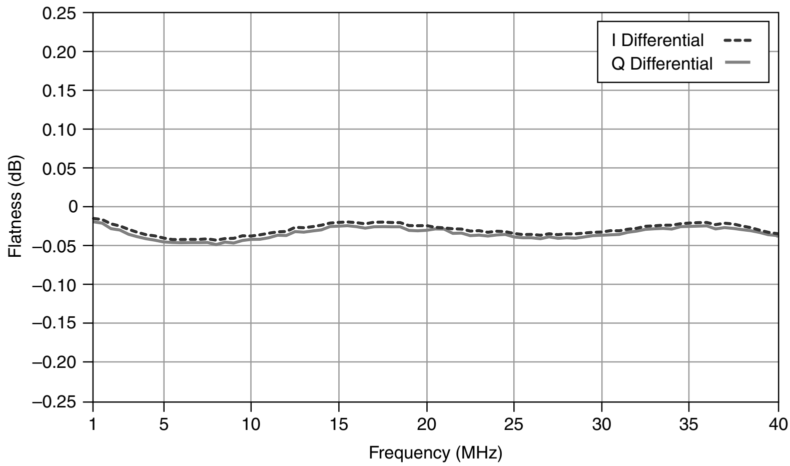
Table 34. I/Q Output Passband Flatness[51] (dB)

I or Q Bandwidth	23 °C ± 5 °C	0 °C to 55 °C
20 MHz	0.42	0.48
	0.13, typical	0.19, typical
40 MHz	0.43	0.49
	0.14, typical	0.20, typical

50 Complex equalized bandwidth is the combined bandwidth of I and Q channels. Valid only when using identical gain and termination settings for each I/Q channel.

51 Referenced to 500 kHz. Valid only when using identical gain and termination settings for each I/Q channel.

Figure 29. I/Q Output Passband Flatness[51]



Channel-to-Channel Gain Imbalance

Table 35. I/Q Output Gain Imbalance[52] (dB)

Complex Bandwidth	23 °C ± 5 °C	0 °C to 55 °C
40 MHz	0.02	0.06
	0.015, typical	0.04, typical
80 MHz	0.025	0.065
	0.02, typical	0.045, typical

Channel-to-Channel Phase Matching

Table 36. I/Q Output Phase Matching[53] (Degrees)

Complex Bandwidth	23 °C ± 5 °C	0 °C to 55 °C
40 MHz	0.1	0.15
	0.05, typical	0.1, typical
80 MHz	0.125	0.15
	0.08, typical	0.1, typical

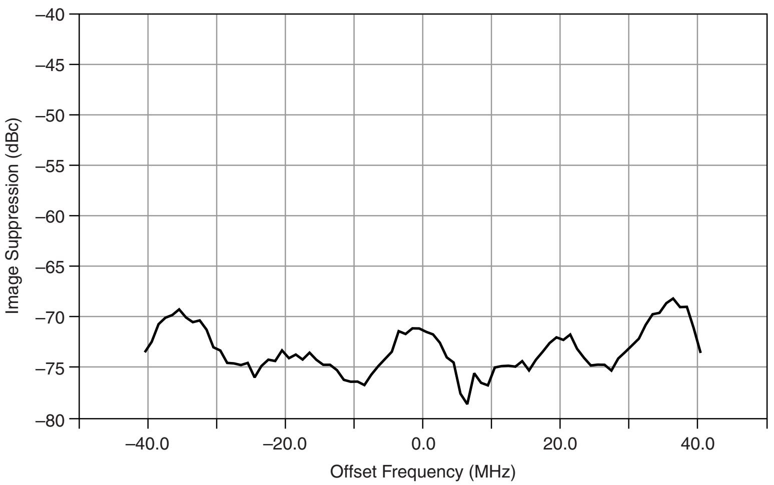
52 Valid only when using identical gain and termination settings for each I/Q channel.
53 Valid only when using identical gain and termination settings for each I/Q channel.

Image Suppression

Table 37. I/Q Output Image Suppression[54] (dBc)

Complex Bandwidth	23 °C ± 5 °C
40 MHz	-62
	-65, typical
80 MHz	-55
	-60, typical
Image suppression is equivalent or better than specification at all frequency offsets within the specified bandwidth. For ambient temperatures from 0 °C to 55 °C, image suppression is -50 dBc, typical over 80 MHz of complex bandwidth. External calibration is recommended to optimize performance for a specific ambient temperature outside of 23 °C ± 5 °C.	

Figure 30. I/Q Output Image Suppression, Nominal

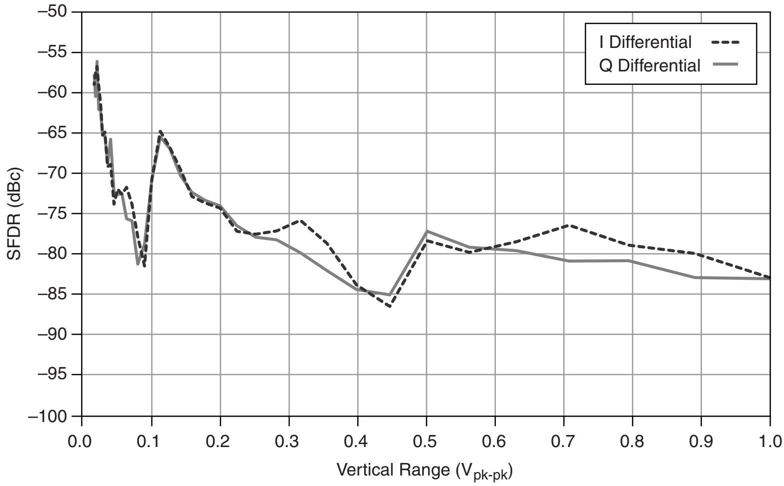


54 Digital equalization enabled. Valid only when using identical gain and termination settings for each I/Q channel.

Spectral Characteristics

SFDR

Figure 31. Measured I/Q Output SFDR, 9.9 MHz Signal

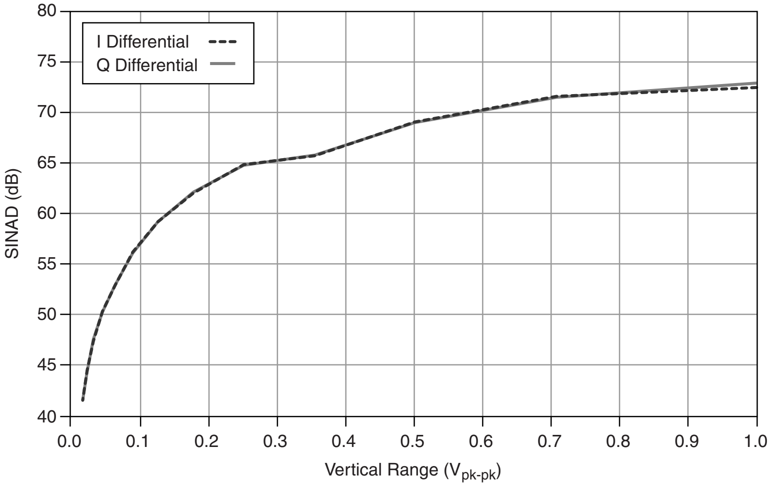


SINAD

I/Q output SINAD[55] (dB)	
23 °C ± 5 °C	66, typical
0 °C to 55 °C	64, typical

55 Generated -1 dBFS CW at 9.9 MHz. Includes harmonic and nonharmonic content. Short pattern waveforms may degrade the distortion performance by 3 dB.

Figure 32. Measured I/Q Output SINAD[55]

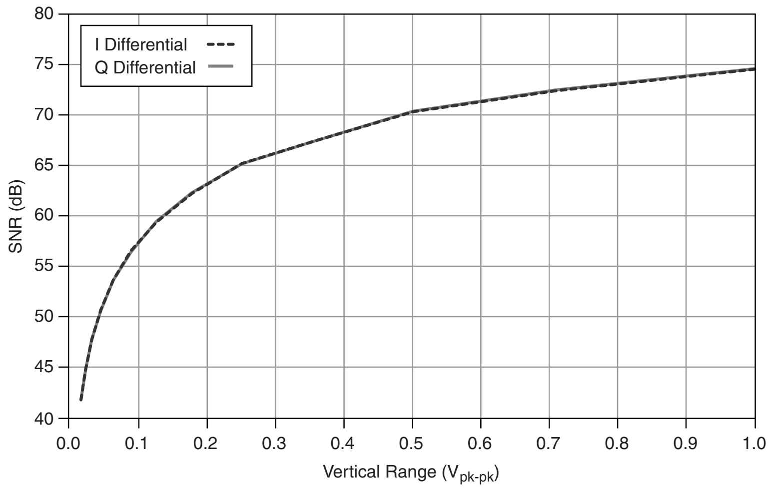


SNR

I/Q output SNR[56] (dB)	
23 °C ± 5 °C	66, typical
0 °C to 55 °C	64, typical

[56] Generated -1 dBFS CW at 9.9 MHz.

Figure 33. Measured I/Q Output SNR[56]

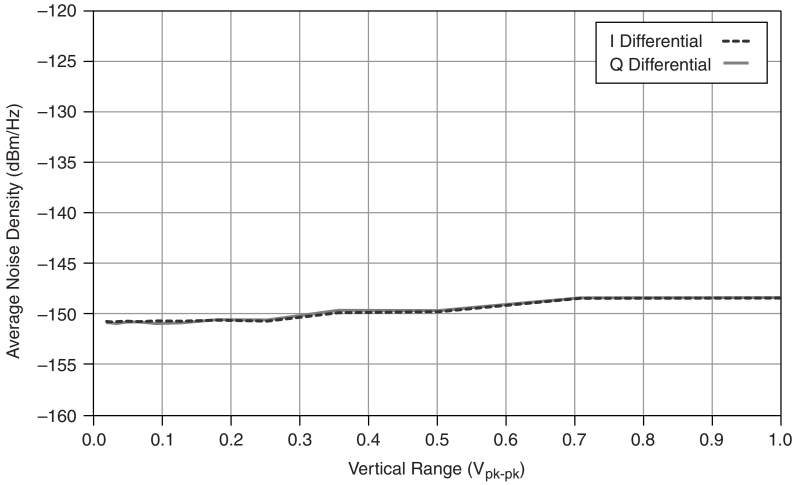


Average Noise Density

I/Q output average noise density[57] (dBm/Hz)	
23 °C ± 5 °C	-149, typical
0 °C to 55 °C	-147, typical

[57] Terminated into 50 Ω.

Figure 34. Measured I/Q Output Noise Density[57]

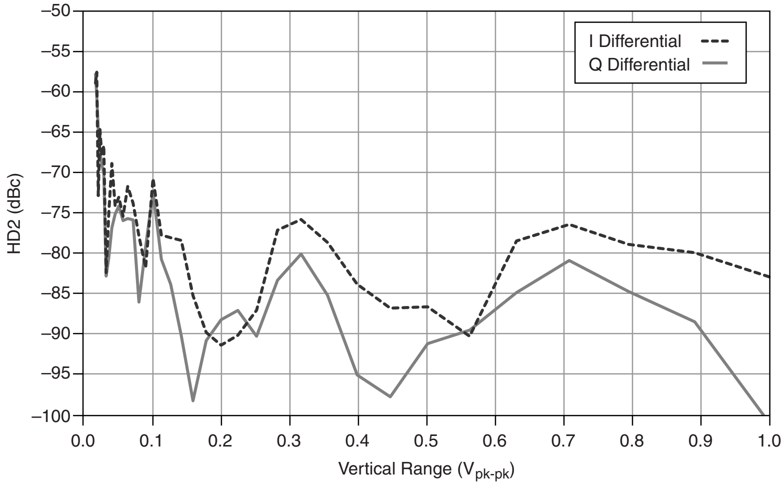


Harmonics

I/Q output second harmonic[58] (dBc)	
23 °C ± 5 °C	-75, typical
0 °C to 55 °C	-73, typical

[58] Generated -1 dBFS CW at 9.9 MHz.

Figure 35. Measured I/Q Output Second Harmonic[58]



I/Q output third harmonic[58] (dBc)	
23 °C ± 5 °C	-84, typical
0 °C to 55 °C	-83, typical

Figure 36. Measured I/Q Output Third Harmonic[58]

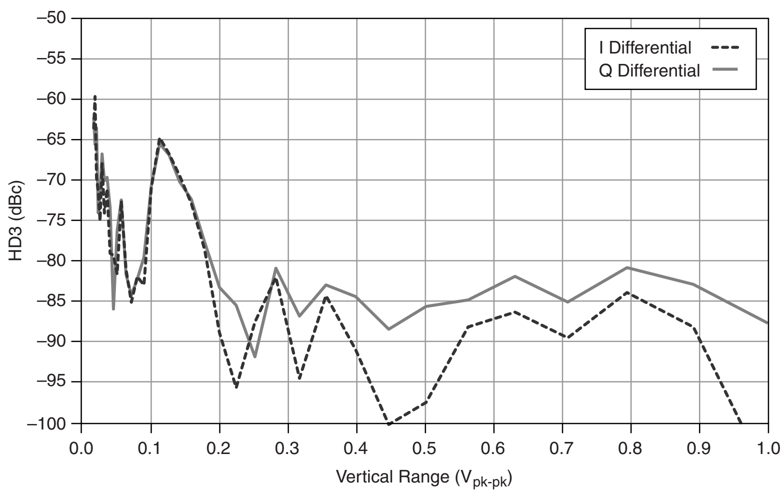
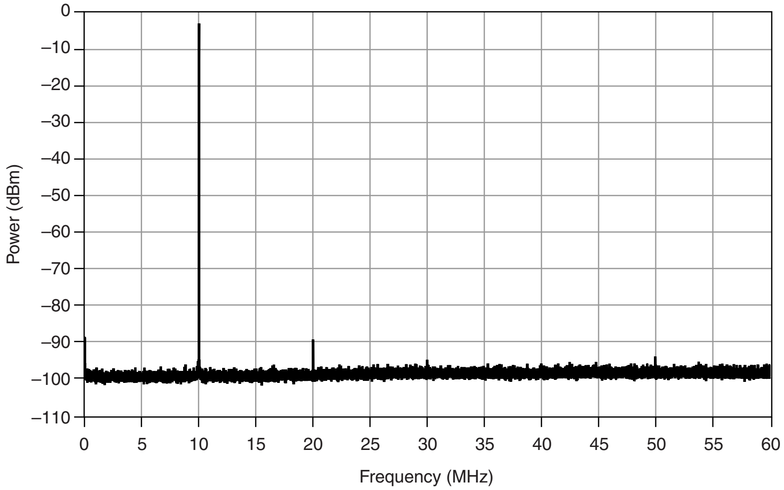


Figure 37. Measured I/Q Output Single Tone Spectrum



Third-Order Output Intermodulation

I/Q third-order output intermodulation[59] (IMD_3) (dBc)	
23 °C ± 5 °C	-80, typical
0 °C to 55 °C	-75, typical

[59] Generating -7 dBFS CW tones at 9.9 MHz and 10.1 MHz.

Figure 38. Measured I/Q Output IMD_3[59]

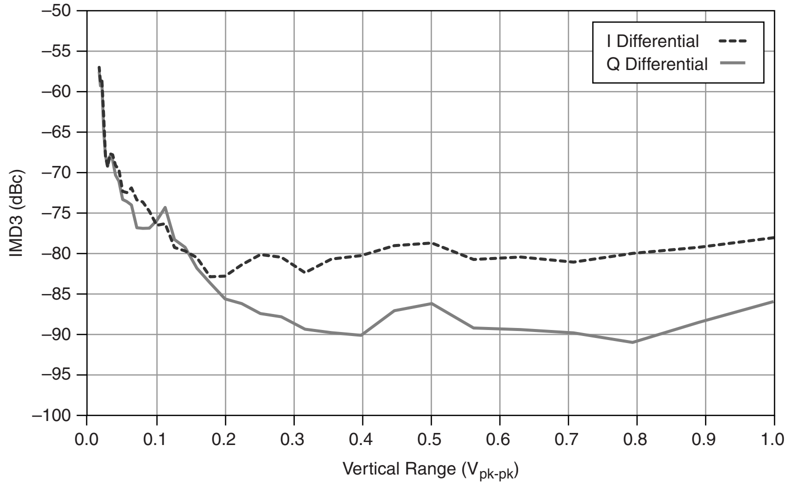
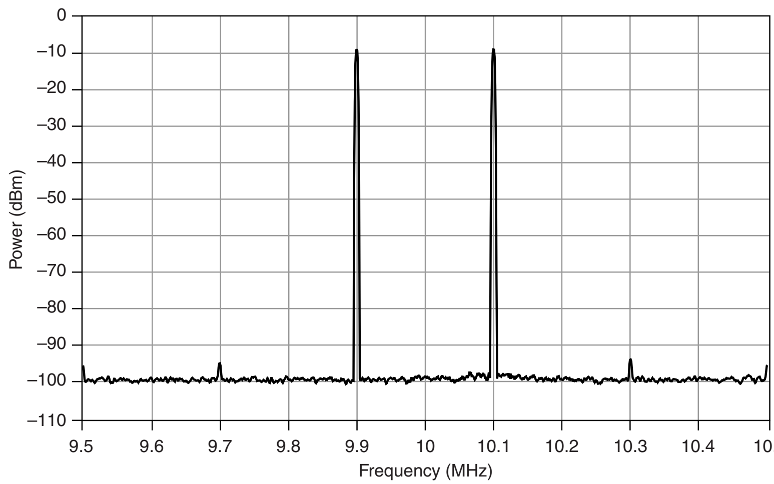


Figure 39. Measured I/Q Output Two-Tone Spectrum

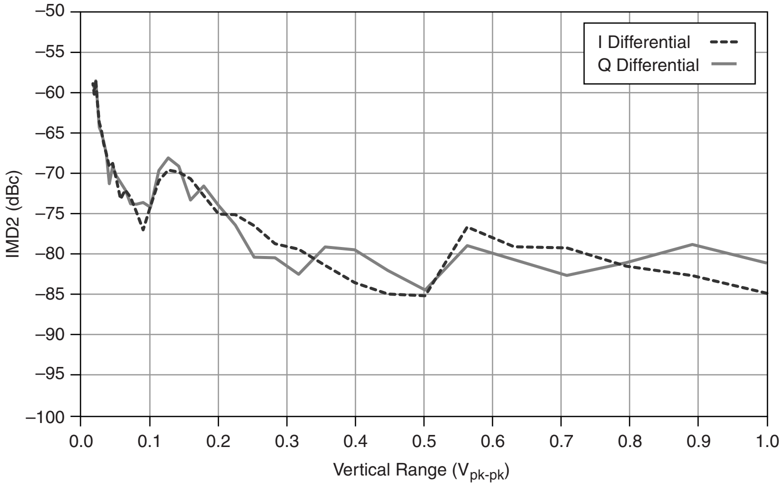


Second-Order Output Intermodulation

I/Q second-order output intermodulation[60] (IMD_2) (dBc)	
23 °C ± 5 °C	-80, typical
0 °C to 55 °C	-75, typical

60 Generating -1 dBFS CW tones at 9.9 MHz and 10.1 MHz.

Figure 40. I/Q Output IMD_2[60]



Application-Specific Modulation Quality

Typical performance assumes the NI 5645R is operating within ± 5 °C of the previous self-calibration temperature, and that the ambient temperature is 0 °C to 55 °C.

RF Application-Specific Modulation Quality

WLAN 802.11ac

OFDM[61]	-45 EVM (rms) dB, typical

WLAN 802.11n

Table 38. 802.11n OFDM EVM (rms) (dB), Typical

Frequency	20 MHz Bandwidth	40 MHz Bandwidth
2,412 MHz	-50	-50
5,000 MHz	-48	-46
Conditions: RF OUT loopback to RF IN; average power: -10 dBm; reference level: auto-leveled based on real-time average power measurement; 20 packets; 3/4 coding rate; 64 QAM.		

61 Conditions: RF OUT loopback to RF IN; 5,800 MHz; 80 MHz bandwidth; average power: -30 dBm to -5 dBm; 20 packets; 16 OFDM data symbols; MCS=9; 256 QAM.

WLAN 802.11a/g/j/p

Table 39. 802.11a/g/j/p OFDM EVM (rms) (dB), Typical

Frequency	20 MHz Bandwidth
2,412 MHz	-53
5,000 MHz	-50
Conditions: RF OUT loopback to RF IN; average power: -10 dBm; reference level: auto-leveled based on real-time average power measurement; 20 packets; 3/4 coding rate; 64 QAM.	

WLAN 802.11g

Table 40. 802.11g DSSS-OFDM EVM (rms) (dB), Typical

Frequency	20 MHz Bandwidth
2,412 MHz	-53
5,000 MHz	-50
Conditions: RF OUT loopback to RF IN; average power: -10 dBm; reference level: auto-leveled based on real-time average power measurement; 20 packets; 3/4 coding rate; 64 QAM.	

WLAN 802.11b/g

DSSS[62]	-48 EVM (rms) dB, typical

LTE

Table 41. SC-FDMA[63] (Uplink FDD) EVM (rms) (dB), Typical

Frequency	5 MHz Bandwidth	10 MHz Bandwidth	20 MHz Bandwidth
700 MHz	-56	-56	-54
900 MHz	-55	-55	-53
1,430 MHz	-54	-54	-53
1,750 MHz	-51	-50	-50

62 Conditions: RF OUT loopback to RF IN; 2,412 MHz; 20 MHz bandwidth; average power -10 dBm; reference level: auto-leveled based on real-time average power measurement; averages: 10; pulse-shaping filter: Gaussian reference; CCK 11 Mbps.

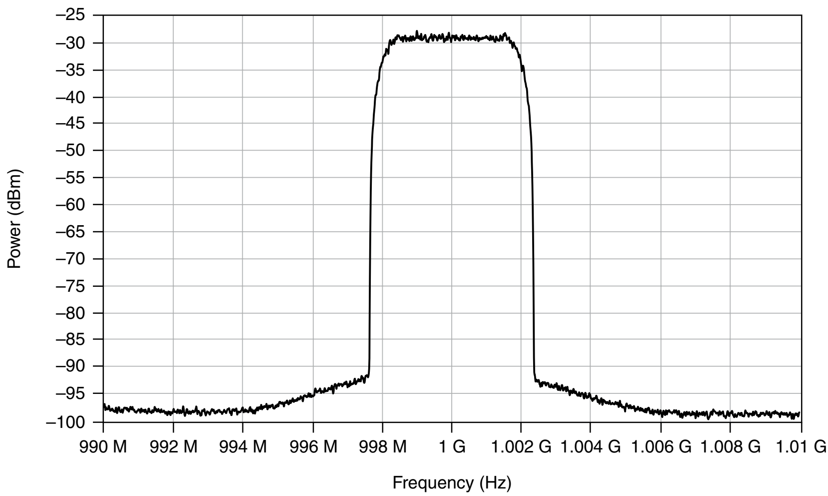
63 Single channel uplink only.

Table 41. SC-FDMA[63] (Uplink FDD) EVM (rms) (dB), Typical (Continued)

Frequency	5 MHz Bandwidth	10 MHz Bandwidth	20 MHz Bandwidth
1,900 MHz	-51	-50	-50
2,500 MHz	-50	-49	-49

WCDMA

Figure 41. WCDMA Measured Spectrum[64] (ACP)



I/Q Baseband Application-Specific Modulation Quality

WLAN 802.11ac

OFDM[65]	-53 EVM (rms) dB, nominal

WLAN 802.11n

OFDM[66]	-54 EVM (rms) dB, nominal

63 Single channel uplink only.

64 Conditions: DL Test Model 1 (64DPCH); RF output level: -10 dBm average; RF OUT loopback to RF IN; measured results better than -66 dB.

65 Conditions: I/Q OUT loopback to I/Q IN; 0.5 $V_{pk\text{-}pk}$ range, differential; 80 MHz bandwidth; 20 packets; 16 OFDM data symbols; MCS=9; 256 QAM.

66 Conditions: I/Q OUT loopback to I/Q IN; 0.5 $V_{pk\text{-}pk}$ range, differential; 20 MHz, 40 MHz bandwidth; 20 packets; 3/4 coding rate; 64 QAM.

WLAN 802.11a/g/j/p

OFDM[67]	-58 EVM (rms) dB, nominal

WLAN 802.11g

DSSS-OFDM[68]	-56 EVM (rms) dB, nominal

WLAN 802.11b/g

DSSS[69]	-51 EVM (rms) dB, nominal

LTE

SC-FDMA[70] (Uplink FDD)	-56 channel EVM (rms) dB, nominal

Baseband Characteristics

Analog-to-digital converters (ADCs)	
Resolution	16 bits
Sample rate[71]	120 MS/s
I/Q data rate[72]	1.84 kS/s to 120 MS/s
Digital-to-analog converters (DACs)	
Resolution	16 bits
Sample rate[73]	120 MS/s
I/Q data rate[74]	1.84 kS/s to 120 MS/s

Onboard FPGA

FPGA	Xilinx Virtex-6 LX195T
LUTs	124,800

67 Conditions: I/Q OUT loopback to I/Q IN; 0.5 V_{pk-pk} range, differential; 20 MHz bandwidth; 20 packets; 3/4 coding rate; 64 QAM.
68 Conditions: I/Q OUT loopback to I/Q IN; 0.5 V_{pk-pk} range, differential; 20 MHz bandwidth; 20 packets; 3/4 coding rate; 64 QAM.
69 Conditions: I/Q OUT loopback to I/Q IN; 0.5 V_{pk-pk} range, differential; 20 MHz bandwidth; Averages: 10; Pulse shaping filter: Gaussian; CCK: 11 Mbps.
70 Conditions: I/Q OUT loopback to I/Q IN; 0.5 V_{pk-pk} range, differential; 5 MHz, 10 MHz, 20 MHz bandwidth; single channel uplink only; 64 QAM PUSCH modulation.
71 ADCs are dual-channel components with each channel assigned to I and Q, respectively.
72 I/Q data rates lower than 120 MS/s are achieved using fractional decimation.
73 DACs are dual-channel components with each channel assigned to I and Q, respectively. DAC sample rate is internally interpolated to 960 MS/s, automatically configured.
74 I/Q data rates lower than 120 MS/s are achieved using fractional interpolation.

Flip-flops	249,600
DSP48 slices	640
Embedded block RAM	12,384 kbits
Data transfers	DMA, interrupts, programmed I/O
Number of DMA channels	16

Onboard DRAM

Memory size	2 banks, 256 MB per bank
Theoretical maximum data rate	2.1 GB/s per bank

Onboard SRAM

Memory size	2 MB
Maximum data rate (read)	40 MB/s
Maximum data rate (write)	36 MB/s

Front Panel I/O

RF IN

Connector	SMA (female)
Input impedance	50 Ω, nominal, AC coupled
Maximum DC input voltage without damage	8 V
Absolute maximum input power[75]	+33 dBm (CW RMS)

Input Return Loss (Voltage Standing Wave Ratio (VSWR))

Table 42. Input Return Loss (dB) (VSWR)

Frequency	Typical
109 MHz ≤ f < 2.4 GHz	15.5 (1.40:1)
2.4 GHz ≤ f < 4 GHz	12.7 (1.60:1)
4 GHz ≤ f ≤ 6 GHz	11.0 (1.78:1)
Return loss for frequencies <109 MHz is typically better than 14 dB (VSWR <1.5:1).	

75 For modulated signals, peak instantaneous power not to exceed +36 dBm.

RF OUT

Connector	SMA (female)
Output impedance	50 Ω, nominal, AC coupled
Absolute maximum reverse power[76]	
<4 GHz	+33 dBm (CW RMS)
≥4 GHz	+30 dBm (CW RMS)

Output Return Loss (VSWR)

Table 43. Output Return Loss (dB) (VSWR)

Frequency	Typical
109 MHz ≤ f < 2 GHz	19.0 (1.25:1)
2 GHz ≤ f < 5 GHz	14.0 (1.50:1)
5 GHz ≤ f ≤ 6 GHz	11.0 (1.78:1)
Return loss for frequencies <109 MHz is typically better than 20 dB (VSWR <1.22:1).	

CAL IN, CAL OUT

Connector	SMA (female)
Impedance	50 Ω, nominal

Caution Do not disconnect the cable that connects CAL IN to CAL OUT. Removing the cable from or tampering with the CAL IN or CAL OUT front panel connectors voids the product calibration and specifications are no longer warranted.

LO OUT (RF IN 0 and RF OUT 0)

Connectors	SMA (female)
Frequency range[77]	65 MHz to 6 GHz
Power	
LO OUT (RF IN 0) 65 MHz to 6 GHz	0 dBm ±2 dB, typical

76 For modulated signals, peak instantaneous power not to exceed corresponding peak power of specified CW.

77 When tuning to 65 MHz to 375 MHz using the RF IN channel, the exported LO is twice the RF frequency requested.

LO OUT (RF OUT 0)	
65 MHz to 3.6 GHz	0 dBm ±2 dB, typical
≥3.6 GHz to 6 GHz	3 dBm ±2 dB, typical
Output power resolution	0.25 dB, nominal
Output impedance	50 Ω, nominal, AC coupled
Output return loss	>11.0 dB (VSWR <1.8:1), typical
Output isolation (state: disabled)	
<2.5 GHz tuned LO	-45 dBc, nominal
≥2.5 GHz tuned LO	-35 dBc, nominal

LO IN (RF IN 0 and RF OUT 0)

Connectors	SMA (female)
Frequency range[78]	65 MHz to 6 GHz
Expected input power	
LO IN (RF IN 0) 65 MHz to 6 GHz	0 dBm ±3 dB, nominal
LO IN (RF OUT 0)	
65 MHz to 3.6 GHz	0 dBm ±3 dB, nominal
≥3.6 GHz to 6 GHz	3 dBm ±1 dB, nominal
Input impedance	50 Ω, nominal, AC coupled
Input return loss	>11.7 dB (VSWR <1.7:1), typical
Absolute maximum power	+15 dBm
Maximum DC voltage	±5 VDC

I/Q IN 0

Connectors	MCX
DC input resistance	
Single-ended	50 Ω, nominal
Differential	100 Ω, nominal
Input coupling, per terminal	DC
Input return loss ≤ 40 MHz	>-28 dB, nominal

[78] When tuning to 65 MHz to 375 MHz using the RF IN channel, the exported LO is twice the RF frequency requested.

Input type	Single-ended[79], differential
Number of channels	2

I/Q OUT 0

Connectors	MCX
DC output resistance	
Single-ended	50 Ω, nominal
Differential	100 Ω, nominal
Output coupling, per terminal	DC
Output return loss ≤ 40 MHz	>-28 dB, nominal
Output type	Single-ended[80], differential
Number of channels	2

REF IN

Connector	SMA (female)
Frequency	10 MHz
Tolerance[81]	$\pm 10 \times 10^{-6}$
Amplitude	
Square	0.7 $V_{pk\text{-}pk}$ to 5.0 $V_{pk\text{-}pk}$ into 50 Ω, typical
Sine[82]	1.4 $V_{pk\text{-}pk}$ to 5.0 $V_{pk\text{-}pk}$ into 50 Ω, typical
Input impedance	50 Ω, nominal
Coupling	AC

REF OUT

Connector	SMA (female)
Frequency	
Reference Clock[83]	10 MHz, nominal
Sample Clock	120 MHz, nominal
Amplitude	1.65 $V_{pk\text{-}pk}$ into 50 Ω, nominal

79 Negative terminal must be externally terminated in single-ended mode.
80 Negative terminal must be externally terminated in single-ended mode.
81 Frequency accuracy = tolerance × reference frequency
82 1 V_{rms} to 3.5 V_{rms}, typical. Jitter performance improves with increased slew rate of input signal.
83 Refer to the *Internal Frequency Reference* for accuracy.

Output impedance	50 Ω, nominal
Coupling	AC

PFI 0

Connector	SMA (female)
Voltage levels[84]	
Absolute maximum input range	-0.5 V to 5.5 V
V_{IL}	0.8 V
V_{IH}	2.0 V
V_{OL}	0.2 V with 100 μA load
V_{OH}	2.9 V with 100 μA load
Input impedance	10 kΩ, nominal
Output impedance	50 Ω, nominal
Maximum DC drive strength	24 mA
Minimum required direction change latency[85]	48 ns + 1 clock cycle

DIGITAL I/O

Connector	VHDCI

Table 44. DIGITAL I/O Signal Characteristics

Signal	Direction	Port Width
DIO <23..20>	Bidirectional, per port	4
DIO <19..16>	Bidirectional, per port	4
DIO <15..12>	Bidirectional, per port	4
DIO <11..8>	Bidirectional, per port	4
DIO <7..4>	Bidirectional, per port	4
DIO <3..0>	Bidirectional, per port	4
PFI 1	Bidirectional	1
PFI 2	Bidirectional	1

84 Voltage levels are guaranteed by design through the digital buffer specifications.
85 Clock cycle refers to the FPGA clock domain used for direction control.

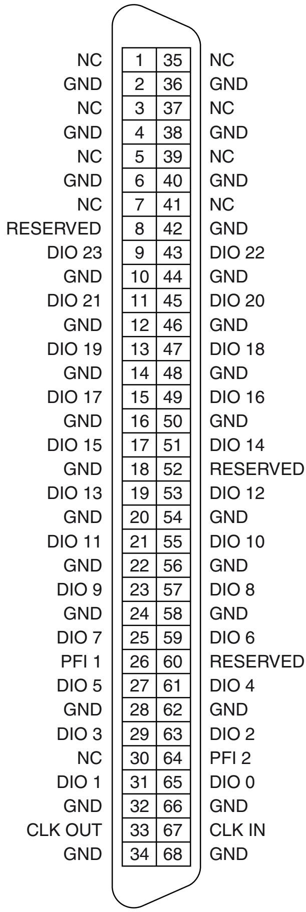
Table 44. DIGITAL I/O Signal Characteristics (Continued)

Signal	Direction	Port Width
Clock In	Input	1
Clock Out	Output	1

Voltage levels[86]	
Absolute maximum input range	-0.5 V to 4.5 V
V_{IL}	0.8 V
V_{IH}	2.0 V
V_{OL}	0.2 V with 100 μA load
V_{OH}	2.9 V with 100 μA load
Input impedance	
DIO <23..0>, CLK IN	10 kΩ, nominal
PFI 1, PFI 2	100 kΩ pull up, nominal
Output impedance	50 Ω, nominal
Maximum DC drive strength	12 mA
Minimum required direction change latency[87]	48 ns + 1 clock cycle
Maximum toggle rate	125 MHz, typical

[86] Voltage levels are guaranteed by design through the digital buffer specifications.
[87] Clock cycle refers to the FPGA clock domain used for direction control.

Figure 42. DIGITAL I/O VHDCI Connector



Power Requirements

Table 45. Power Requirements

Voltage (V_{DC})	Typical Current (A)	Maximum Current (A)
+3.3	4.9	5.3
+12	3.3	4.2
Power is 56 W, typical. Consumption is from both NI PXI Express backplane power connectors.		

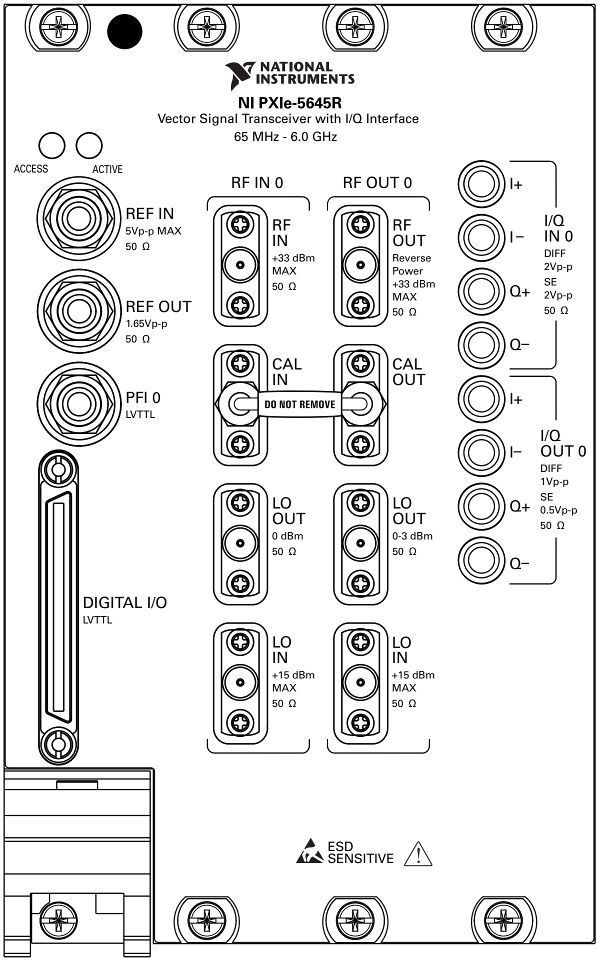
Calibration

Interval	1 year

Note For the two-year calibration interval, add 0.2 dB to one-year specifications for *Absolute Amplitude Accuracy*, RF input *Frequency Response*, *Output Power Level Accuracy*, and RF output *Frequency Response*.

Hardware Front Panel

Figure 43. NI 5645R Front Panel



Physical Characteristics

NI 5645R module	3U, four slot, PXI Express module 8.1 cm × 12.9 cm × 21.1 cm 3.2 in × 5.6 in × 8.3 in
Weight	1,758 g (62.0 oz)

Environment

Maximum altitude	2,000 m (800 mbar) (at 25 °C ambient temperature)
Pollution Degree	2

Indoor use only.

Operating Environment

Ambient temperature range	0 °C to 55 °C (Tested in accordance with IEC 60068-2-1 and IEC 60068-2-2. Meets MIL-PRF-28800F Class 3 low temperature limit and MIL-PRF-28800F Class 2 high temperature limit.)
Relative humidity range	10% to 90%, noncondensing (Tested in accordance with IEC 60068-2-56.)

Storage Environment

Ambient temperature range	-40 °C to 71 °C (Tested in accordance with IEC 60068-2-1 and IEC 60068-2-2. Meets MIL-PRF-28800F Class 3 limits.)
Relative humidity range	5% to 95%, noncondensing (Tested in accordance with IEC 60068-2-56.)

Shock and Vibration

Operating shock	30 g peak, half-sine, 11 ms pulse (Tested in accordance with IEC 60068-2-27. Meets MIL-PRF-28800F Class 2 limits.)

Random vibration	
Operating	5 Hz to 500 Hz, 0.3 g_{rms}
Nonoperating	5 Hz to 500 Hz, 2.4 g_{rms} (Tested in accordance with IEC 60068-2-64. Nonoperating test profile exceeds the requirements of MIL-PRF-28800F, Class 3.)

Compliance and Certifications

Safety

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

Note For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Basic immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- EN 55022 (CISPR 22): Class A emissions
- EN 55024 (CISPR 24): Immunity
- AS/NZS CISPR 11: Group 1, Class A emissions
- AS/NZS CISPR 22: Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

Note In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia, and New Zealand (per CISPR 11), Class A equipment is intended for use only in heavy-industrial locations.

Note Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generate radio frequency energy for the treatment of material or inspection/analysis purposes.

Note For EMC declarations, certifications, and additional information, refer to the *Online Product Certification* section.

CE Compliance

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)

Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit *ni.com/certification*, search by model number or product line, and click the appropriate link in the Certification column.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at *ni.com/environment*. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers At the end of the product life cycle, all NI products must be disposed of according to local laws and regulations. For more information about how to recycle NI products in your region, visit *ni.com/environment/weee*.

电子信息产品污染控制管理办法（中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令(RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

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