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SPECIFICATIONS

# PXIe-5645

Reconfigurable 6 GHz Vector Signal Transceiver with I/Q Interface

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# Definitions

*Warranted* specifications describe the performance of a model under stated operating conditions and are covered by the model warranty.



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*Characteristics* describe values that are relevant to the use of the model under stated operating conditions but are not covered by the model warranty.

- *Typical* specifications describe the expected performance met by a majority of the models.
- *2σ* specifications describe the 95th percentile values, in which 95% of the cases are met with a 95% confidence.
- *Nominal* specifications describe parameters and attributes that may be useful in operation.

Within the specifications, self-calibration °C refers to the recorded device temperature of the last successful self-calibration.

Specifications are *Warranted* unless otherwise noted.

# Conditions

Specifications are valid under the following conditions unless otherwise noted.

- 30 minutes warm-up time.
- Calibration cycle 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.
- The cable connecting CAL IN to CAL OUT has not been removed or tampered with.
- 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



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# 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 |

# 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 |
| ≤1 × $10^{-6}$ of final frequency | 1.1 | 0.95 | 0.38 |
| ≤0.1 × $10^{-6}$ 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 | ±200 × $10^{-9}$ |
| Temperature stability | ±1 × $10^{-6}$, maximum |

[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.

[3] Medium loop bandwidth is available only in fractional mode.



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| | |
|---|---|
| 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.

# 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 |



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

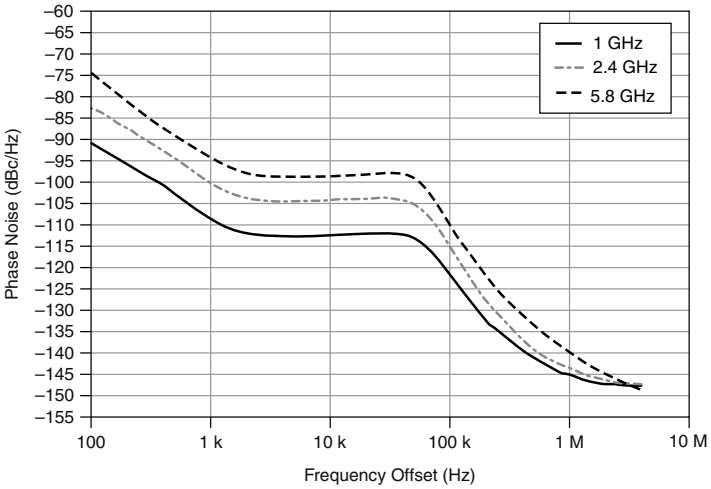
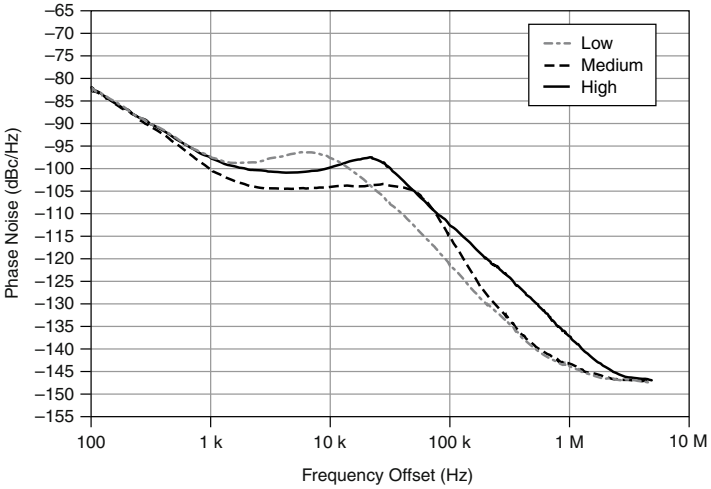



**Figure 2.** Measured Phase Noise[5] at 2.4 GHz Versus Loop Bandwidth




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



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# 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 |

## 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 |

[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.



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**Table 3.** VSA Absolute Amplitude 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 | — | ±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 PXIe-5645 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.



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

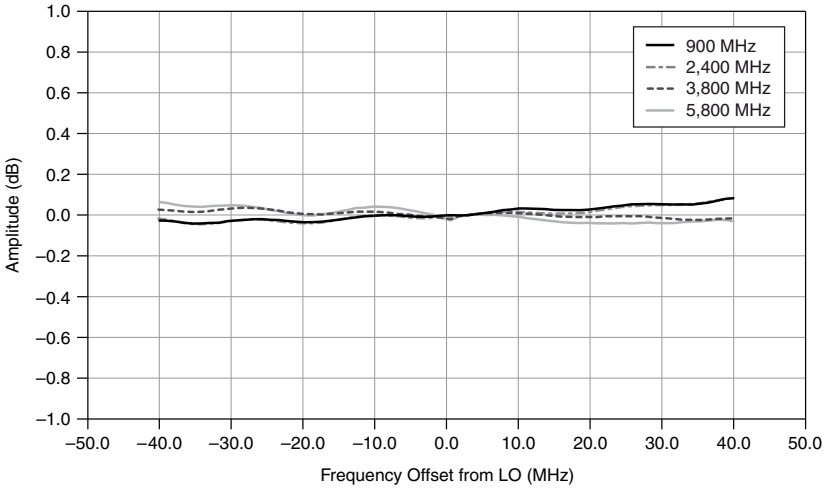
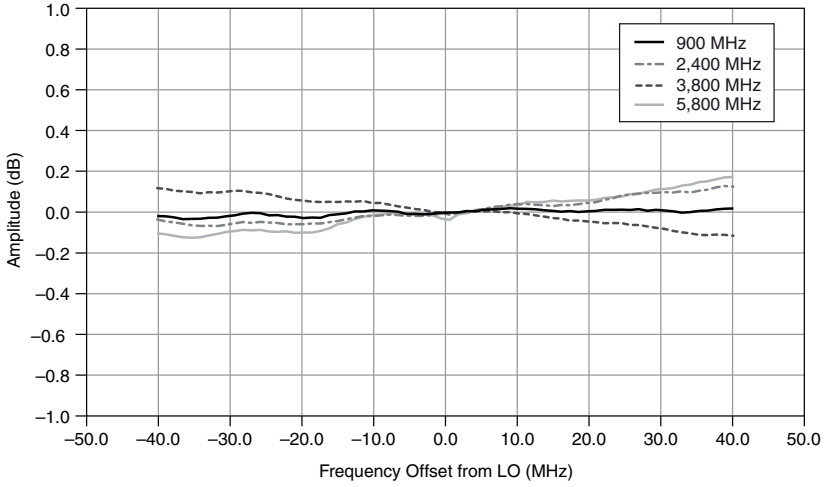



**Figure 4.** Measured Frequency Response,[8] -30 dBm Reference Level, Equalized




[8] Measurement performed after self-calibration.



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# 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.<br>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 |
| | -67, typical | -67, typical |

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



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

| Center Frequency | Self-Calibration °C ± 1 °C | Self-Calibration °C ± 5 °C |
|---|---|---|
| >109 MHz to 375 MHz | — | -58 |
| | -65, typical | -61, typical |
| >375 MHz to 1 GHz | — | -53 |
| | -58, typical | -56, typical |
| 1 GHz to 3 GHz | — | -52 |
| | -58, typical | -56, typical |
| 3 GHz to 4 GHz | — | -44 |
| | -49, typical | -47, typical |
| 4 GHz to 6 GHz | — | -43 |
| | -48, typical | -46, 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.

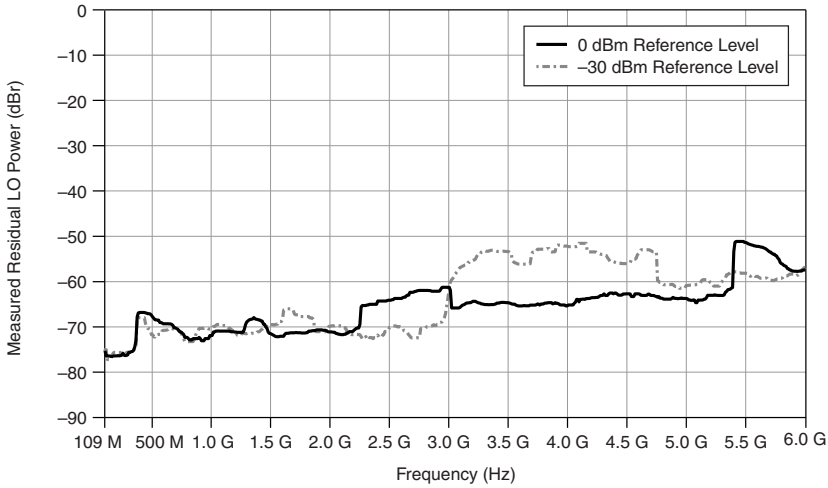
For optimal performance, NI recommends running self-calibration when the PXIe-5645 temperature drifts ± 5 °C from the temperature at the last self-calibration. For temperature changes >±5 °C from self-calibration, LO residual power is -35 dBr.

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



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**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-calibration.



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**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 |

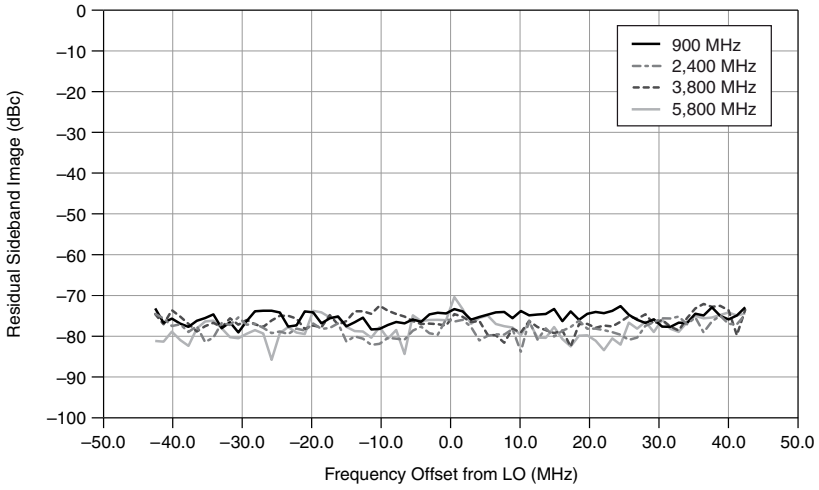
Conditions: Reference levels -30 dBm to +30 dBm.

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 PXIe-5645 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

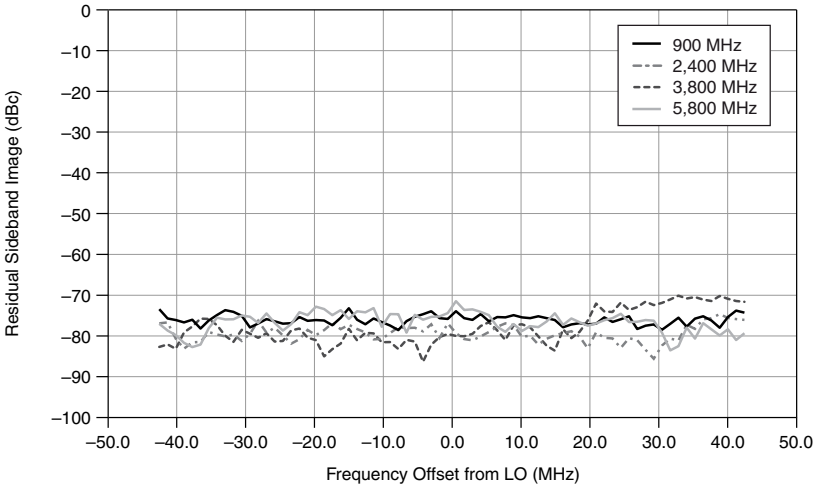



[11] Measurement performed after self-calibration.



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**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 |



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**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[12]

| 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 |

# RF Output

## Power Range

**Table 12.** Power Range

| Output Type | Frequency | Power Range | |
|---|---|---|---|
| CW | <4 GHz | Noise floor to +10 dBm, average power[13] | Noise floor to +15 dBm, average power, nominal |
| | ≥4 GHz | Noise floor to +7 dBm, average power[13] | Noise floor to +12 dBm, average power, nominal |

[12] Conditions: Two -10 dBm tones, 700 kHz apart at RF IN; reference level: -2 dBm; nominal noise floor: -145 dBm/Hz.

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



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**Table 12.** Power Range (Continued)

| Output Type | Frequency | Power Range | |
|---|---|---|---|
| Modulated[14] | <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[15] | 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[16] | 50 µs |
| 0.5 dB of final value[17], 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 |

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



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**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[18] | | ±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 |

[18] 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.



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**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 |

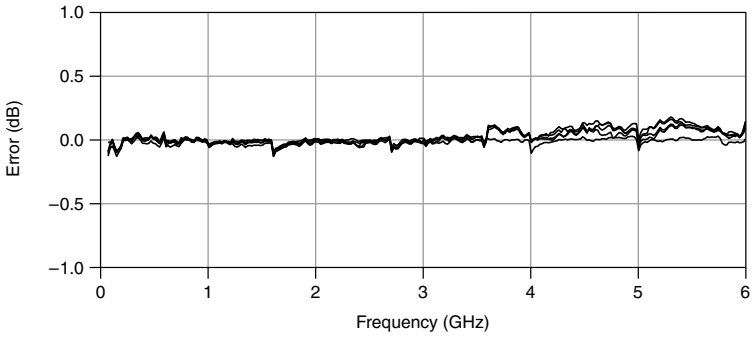
Conditions: CW average power -70 dBm to +10 dBm.

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 PXIe-5645 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





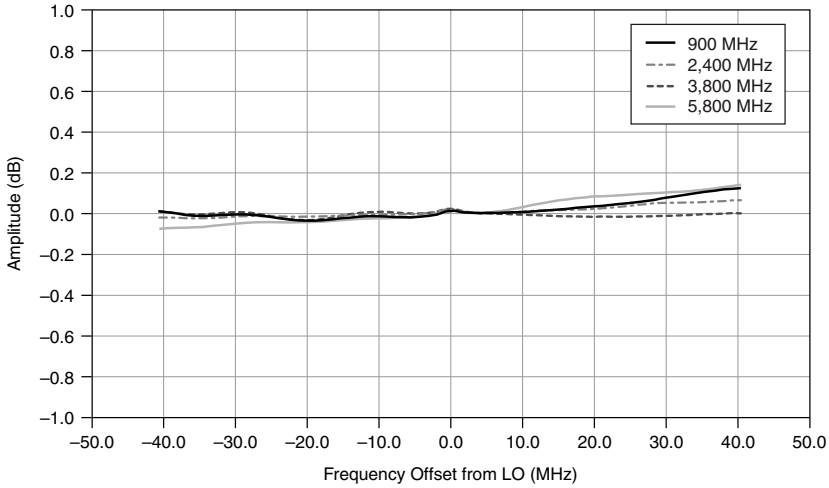

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# Frequency Response

**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[19]




[19] Conditions: Output -10 dBm CW tone. Measurement performed after self-calibration.



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# 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. | | |

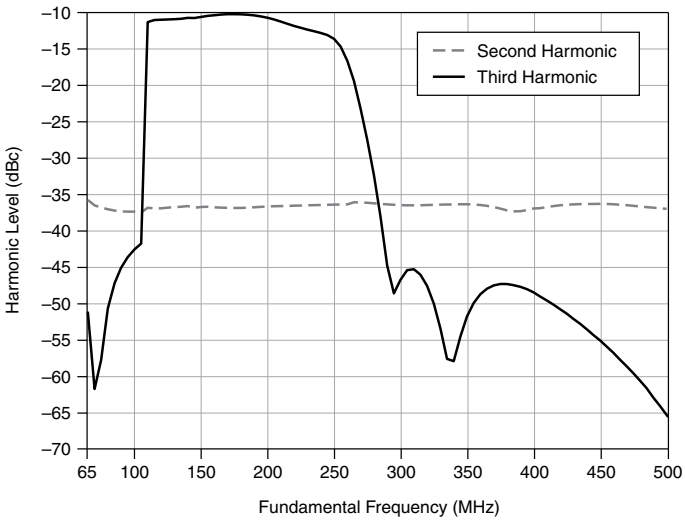
**Note** Higher order harmonic suppression is degraded in the range of 109 MHz to 270 MHz, and third harmonic performance is shown in the following figure. For frequencies outside the range of 109 MHz to 270 MHz, higher order harmonic



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distortion is equal to or better than the second harmonic level as specified in the previous table.

**Figure 10.** Harmonic Level,[20] 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 | -53, typical | -53, typical |

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



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**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.<br>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.<br>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 |



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**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.<br>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 |
| | -57, typical | -55, typical |
| >109 MHz to 375 MHz | — | -42 |
| | -47, typical | -45, typical |
| >375 MHz to 1.6 GHz | — | -55 |
| | -62, typical | -60, typical |
| 1.6 GHz to 2 GHz | — | -54 |
| | -60, typical | -58, typical |
| 2 GHz to 3 GHz | — | -47 |
| | -53, typical | -51, typical |
| 3 GHz to 4 GHz | — | -52 |
| | -57, typical | -55, typical |
| 4 GHz to 5 GHz | — | -51 |
| | -60, typical | -56, typical |



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**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 | — | -47 |
| | -56, typical | -52, 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 PXIe-5645 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,[21] 109 MHz to 6 GHz, Typical

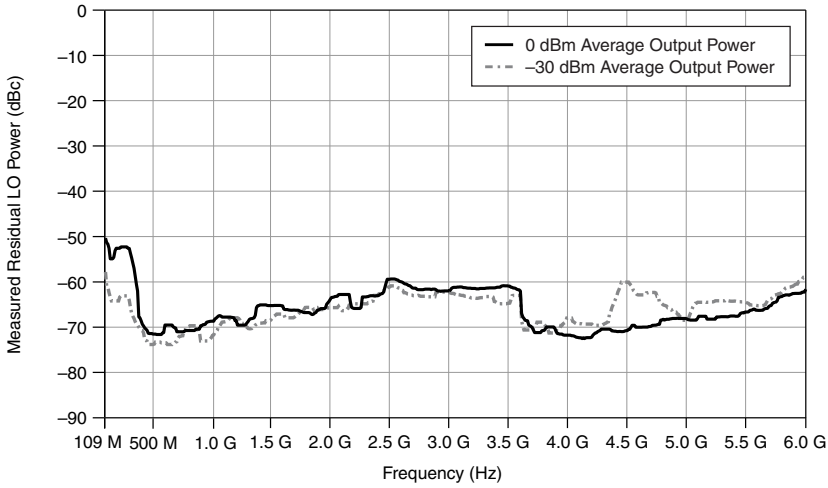



**Table 22.** VSG LO Residual Power (dBc), Low Power

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

[21] Measurement performed after self-calibration.



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**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 PXIe-5645 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 |



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**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 PXIe-5645 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.



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**Figure 12.** VSG Residual Sideband Image,[22] 0 dBm Average Output Power, Typical

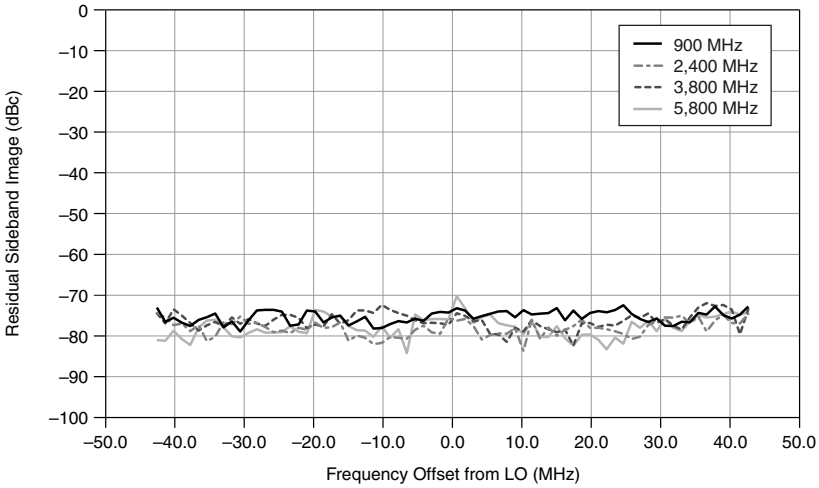
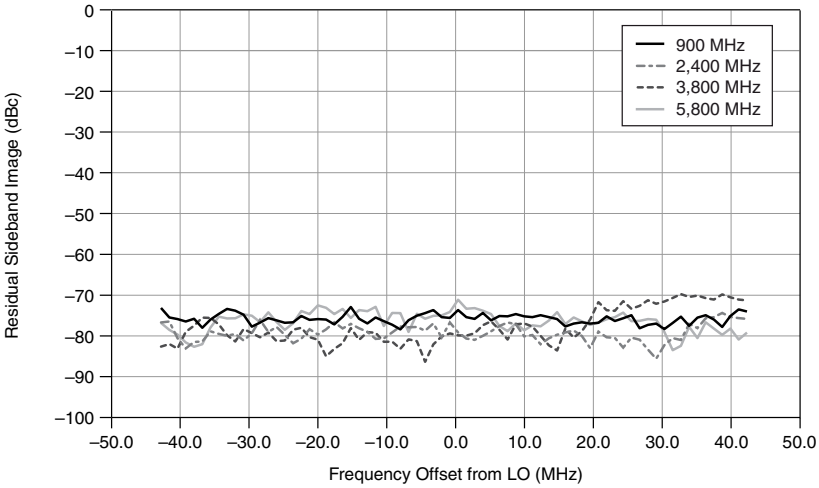



**Figure 13.** VSG Residual Sideband Image,[22] -30 dBm Average Output Power, Typical




[22] Measurement performed after self-calibration.



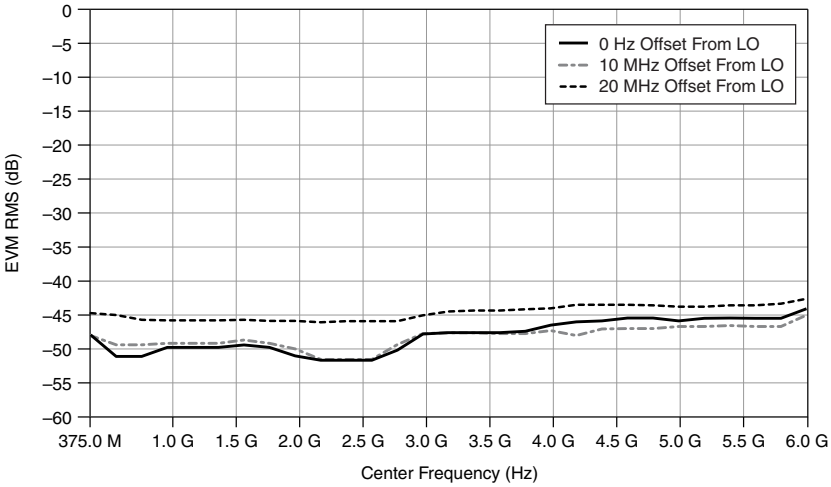
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# Error Vector Magnitude (EVM)

## VSA EVM

20 MHz bandwidth 64-QAM EVM[23] -40 dB, typical
375 MHz to 6 GHz

**Figure 14.** VSA Error Vector Magnitude, Typical[24]




## VSG EVM

20 MHz bandwidth 64-QAM EVM[25] -40 dB, typical
375 MHz to 6 GHz

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

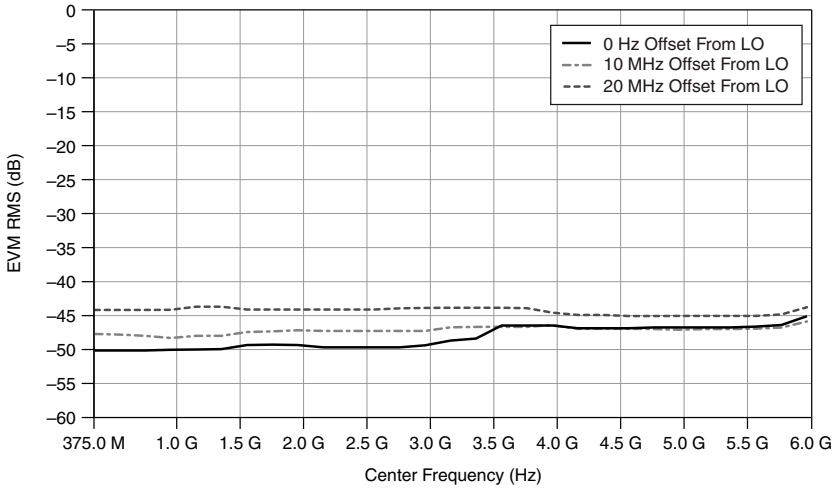
[24] Conditions: 20 MHz bandwidth, 64 QAM; centered at LO frequency or offset digitally as listed.

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



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**Figure 15.** RMS EVM (dB) versus Measured Average Power (dBm), Typical [26]




# I/Q Interface

## Differential and Single-Ended Operation

The I/Q inputs and outputs of the PXIe-5645 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.

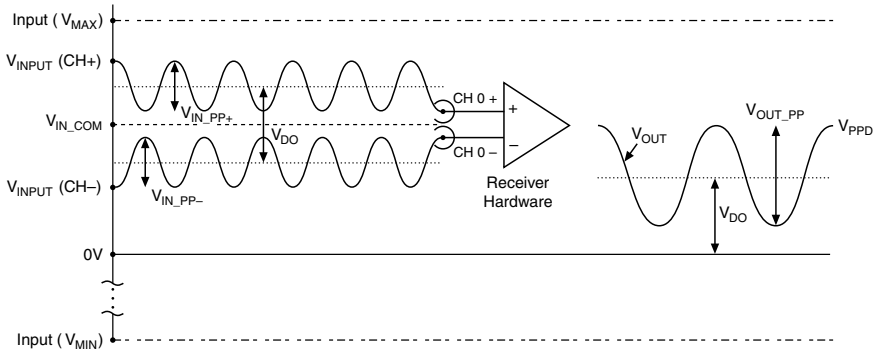
In a differential system, any noise present on both $V_{INPUT}$(CH+) and $V_{INPUT}$(CH-) gets rejected. Differential systems also double the dynamic range compared to a single-ended system with the same voltage swing. The following figure illustrates the key concepts of differential offset and common-mode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

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



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**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.*



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# I/Q Input

## Vertical Range

| | |
|---|---|
| Maximum input voltage | |
| Maximum functional voltage | ± 2.5 V, typical |
| Maximum input voltage[27] (damage) | ±3 V |
| Common-mode range[28] | ±2 V |
| Differential voltage range | |
| Analog | 0.032 $V_{pk-pk}$ to 2 $V_{pk-pk}$ |
| Digital | <0.032 $V_{pk-pk}$ |
| Single-ended voltage range[29] | |
| Analog | 0.032 $V_{pk-pk}$ to 2 $V_{pk-pk}$ |
| Digital | <0.032 $V_{pk-pk}$ |
| 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 |

[27] Common-mode voltage plus peak AC voltage cannot exceed the maximum input voltage of 2.5 V.
[28] Common-mode voltage plus peak AC voltage cannot exceed the maximum input voltage of 2.5 V. Valid for all differential levels.
[29] 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.



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**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:<br>Gain accuracy for temperature within ±5 °C of ambient 23 °C:<br>±(1.75% × 0.5 V) = ±8.75 mV<br><br>Gain accuracy for a temperature at +20 °C above ambient 23 °C:<br>±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[30] (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 |

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



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## Complex Equalized Bandwidth

| | |
|---|---|
| Complex I/Q equalized bandwidth[31] | 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[32] (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 |

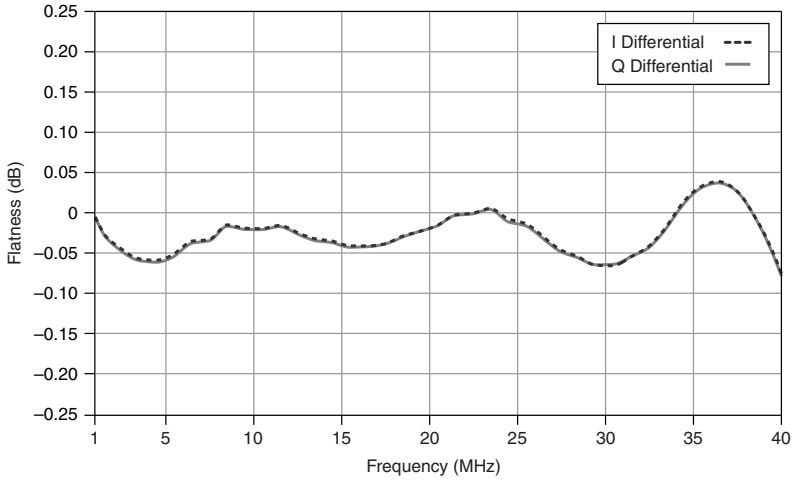
[31] Complex equalized bandwidth is the combined bandwidth of I and Q channels. Valid only when using identical gain and termination settings for each I/Q channel.

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



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**Figure 17.** I/Q Input Passband Flatness[32]




## Channel-to-Channel Gain Imbalance

**Table 28.** I/Q Input Gain Imbalance[33] (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[34] (Degrees)

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

[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.



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**Table 29.** I/Q Input Phase Matching[34] (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[35] (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.<br><br>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. | |

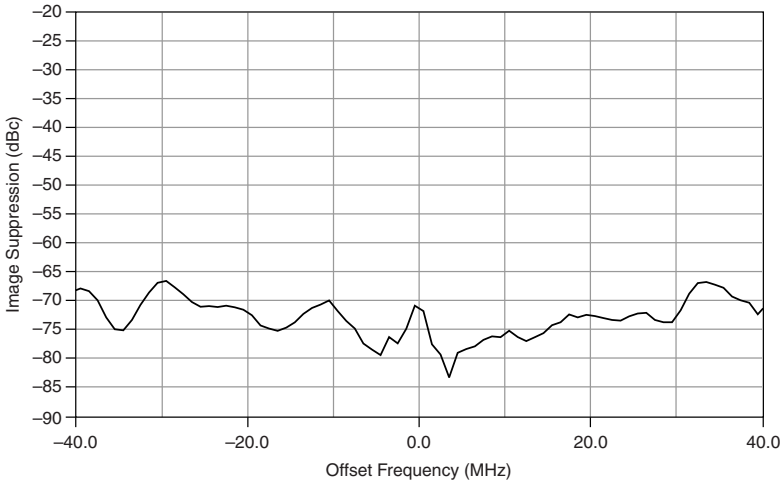
[34] Digital equalization enabled. Valid only when using identical gain and termination settings for each I/Q channel.

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



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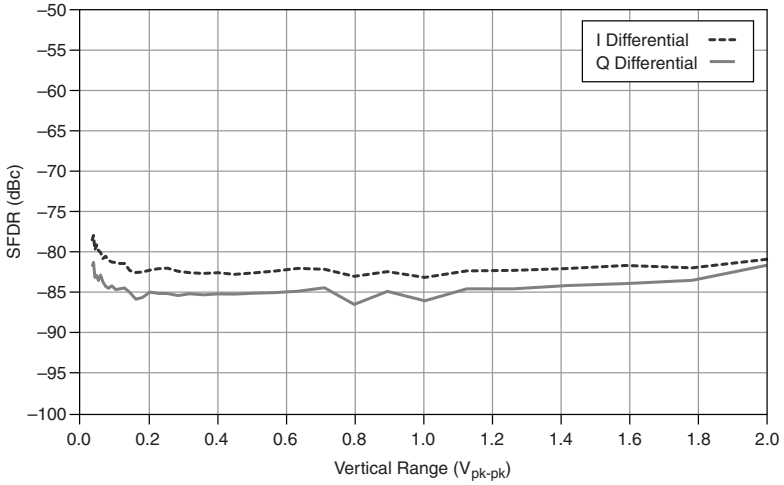
**Figure 18.** I/Q Input Image Suppression,[36] Nominal




## Spectral Characteristics

### Spurious Free Dynamic Range (SFDR)

**Figure 19.** Measured I/Q Input SFDR[37]




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

[37] Measured with a -1 dBFS tone at 9.9 MHz.

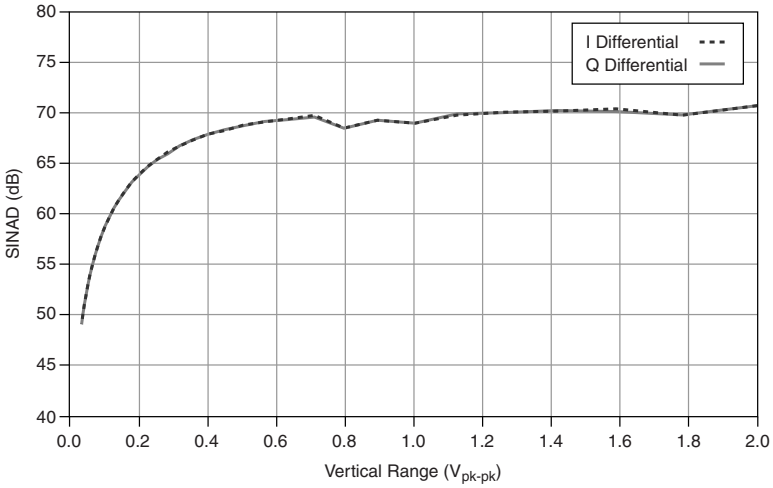


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## Signal to Noise and Distortion (SINAD)

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

**Figure 20.** Measured I/Q Input SINAD[38]




## Signal-to-Noise Ratio (SNR)

| I/Q input SNR[39] (dB) | |
|---|---|
| 23 °C ± 5 °C | 69, typical |
| 0 °C to 55 °C | 67, typical |

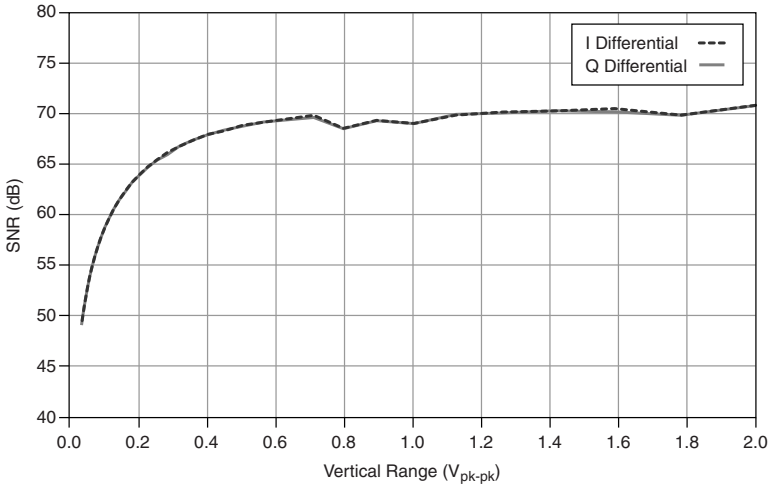
[38] Measured with a fixed -1 dBFS input signal at 9.9 MHz. Specification is valid within 20 MHz of bandwidth for I or Q.

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



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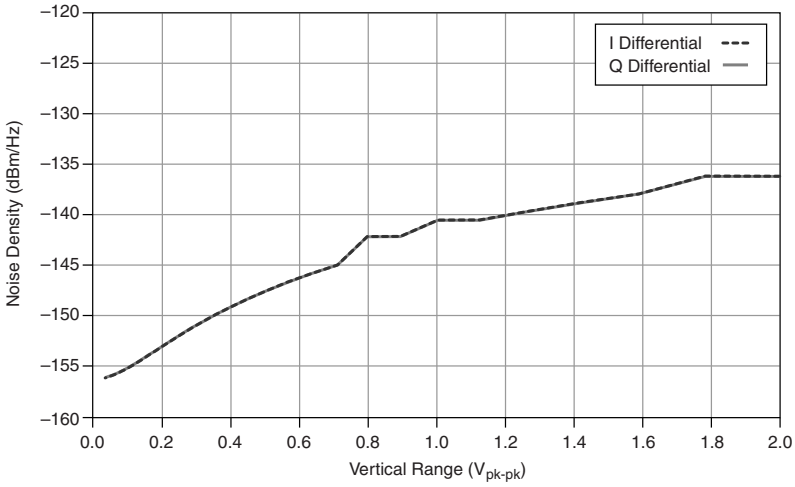
**Figure 21.** I/Q Input SNR[39]




## Average Noise Density

| I/Q input average noise density[40] (dBm/Hz) | |
|---|---|
| 23 °C ± 5 °C | -147, typical |
| 0 °C to 55 °C | -146, typical |

**Figure 22.** Measured I/Q Input Noise Density[40]




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

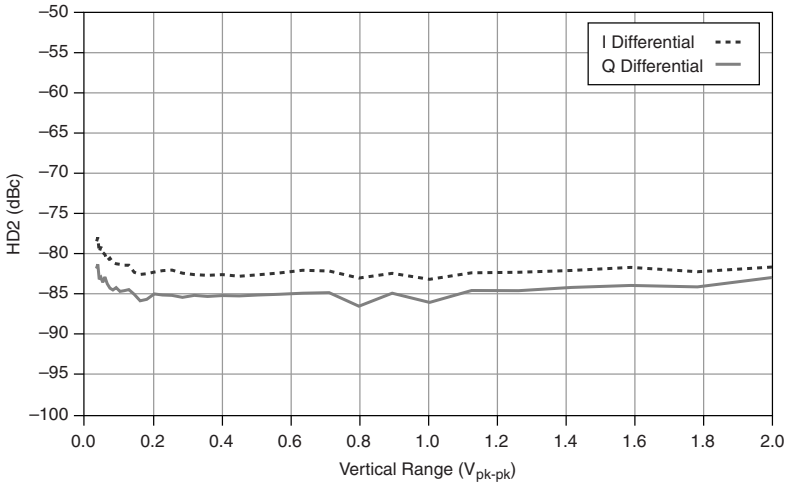


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## Harmonics

| I/Q input second harmonic[41] (dBc) | |
|---|---|
| 23 °C ± 5 °C | -76, typical |
| 0 °C to 55 °C | -75, typical |

**Figure 23.** Measured I/Q Input Second Harmonic[41]




| I/Q input third harmonic[41] (dBc) | |
|---|---|
| 23 °C ± 5 °C | -80, typical |
| 0 °C to 55 °C | -79, typical |

[41] Measured with a -1 dBFS input signal at 9.9 MHz.



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**Figure 24.** Measured I/Q Input Third Harmonic[41]

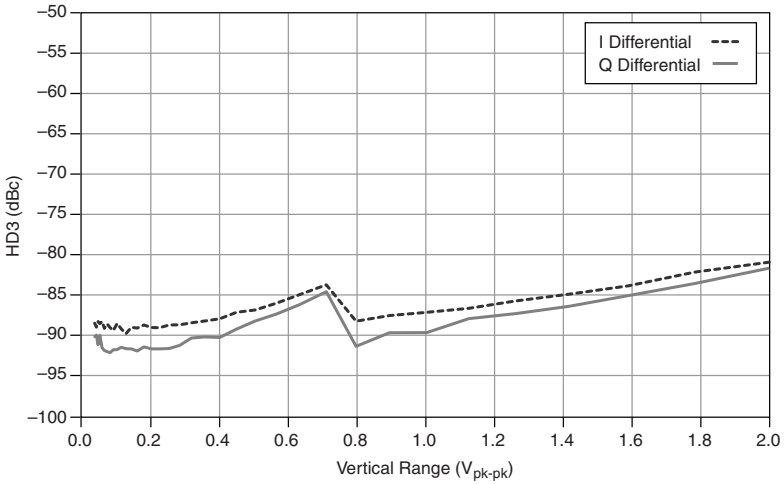
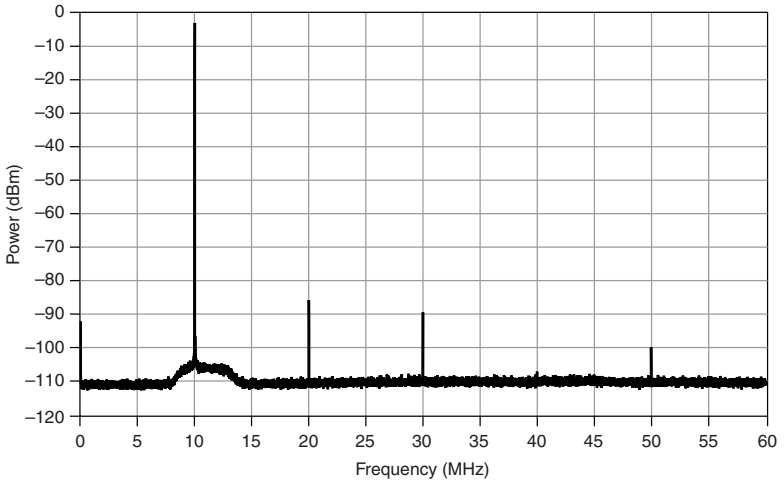



**Figure 25.** Measured I/Q Input Single Tone[42]




[42] Measured with 10 MHz bandpass filter to remove stimulus-related noise and distortion.



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## Third-Order Input Intermodulation

| I/Q third-order input intermodulation[43] ($IMD_3$) (dBc) | |
|---|---|
| 23 °C ± 5 °C | -80, typical |
| 0 °C to 55 °C | -79, typical |

**Figure 26.** Measured I/Q Input $IMD_3$[43]

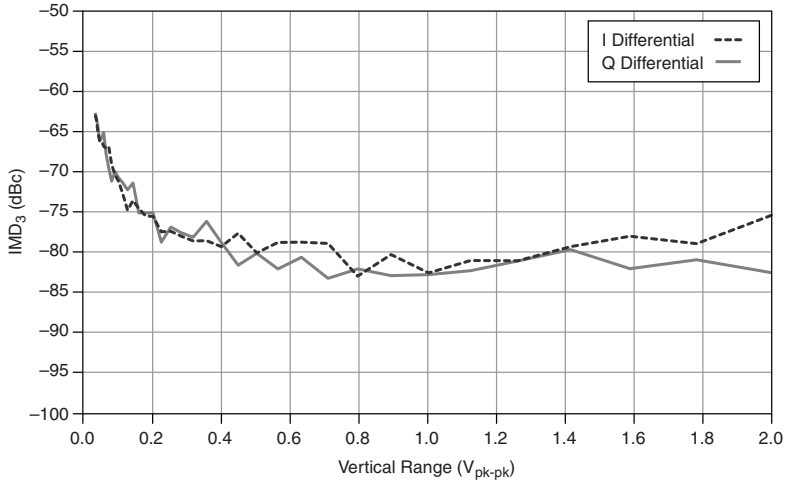
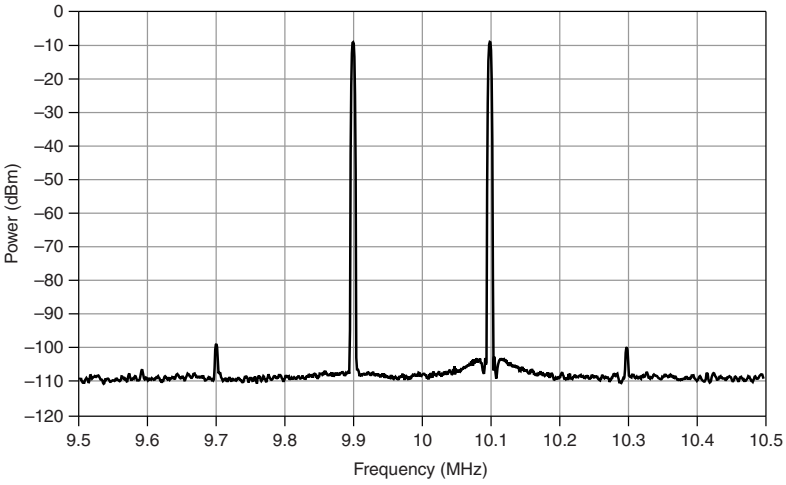



**Figure 27.** Measured I/Q Input Two-Tone Spectrum




[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.

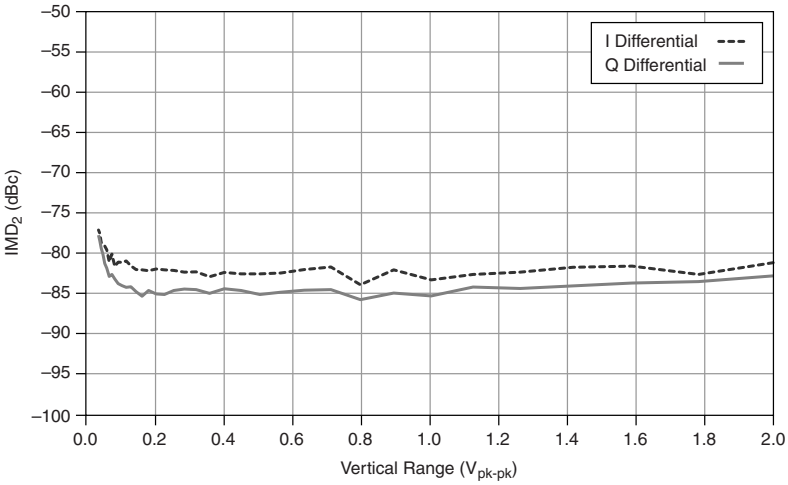


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### Second-Order Input Intermodulation

| | |
|---|---|
| I/Q second-order input intermodulation[44] ($IMD_2$) (dBc) | |
| 23 °C ± 5 °C | -77, typical |
| 0 °C to 55 °C | -75, typical |

**Figure 28.** Measured I/Q Input $IMD_2$[44]




# I/Q Output

## Output Range[45]

| | |
|---|---|
| Maximum output voltage | ±2.5 V |
| Common-mode range[46] | ±2 V |
| Differential voltage range | |
| Analog | $0.032V_{pk-pk}$ to 2 $V_{pk-pk}$ |
| Digital | < 0.032 $V_{pk-pk}$ |

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



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| | |
|---|---|
| Single-ended voltage range[47] | |
| Analog | 0.016 $V_{pk-pk}$ to 1 $V_{pk-pk}$ |
| Digital | < 0.016 $V_{pk-pk}$ |
| 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[48]

| 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:<br>Gain accuracy for temperature within ±5 °C of ambient 23 °C: ±(1.12% × 0.5 V) = ±5.6 mV<br><br>Gain accuracy for a temperature at +20 °C above ambient 23 °C:<br>±5.6 mV - 0.055% × 15 °C × (0.5) = +1.5 mV/-9.8 mV | |

**Table 32.** I/Q Output DC Offset Error[49] (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 |

[47] 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.

[48] Measured with a DMM. Measured with both output terminals terminated to ground through a high impedance.

[49] High-impedance load.



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## Absolute AC Gain Accuracy

**Table 33.** I/Q Output Absolute AC Gain Accuracy[50] (dB)

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

## Complex Equalized Bandwidth

| | |
|---|---|
| Complex I/Q equalized bandwidth[51] | 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[52] (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 Configured for 0 V common-mode, differential. Measured CW at 500 kHz.

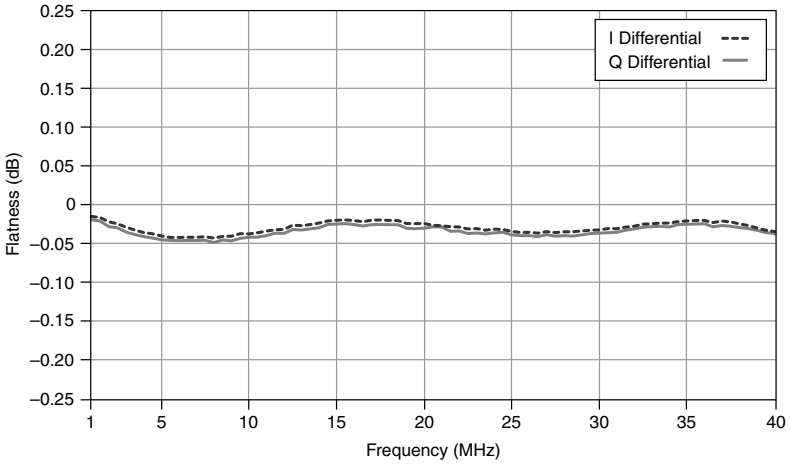
51 Complex equalized bandwidth is the combined bandwidth of I and Q channels. Valid only when using identical gain and termination settings for each I/Q channel.

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



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**Figure 29.** I/Q Output Passband Flatness[52]




## Channel-to-Channel Gain Imbalance

**Table 35.** I/Q Output Gain Imbalance[53] (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[54] (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 |

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



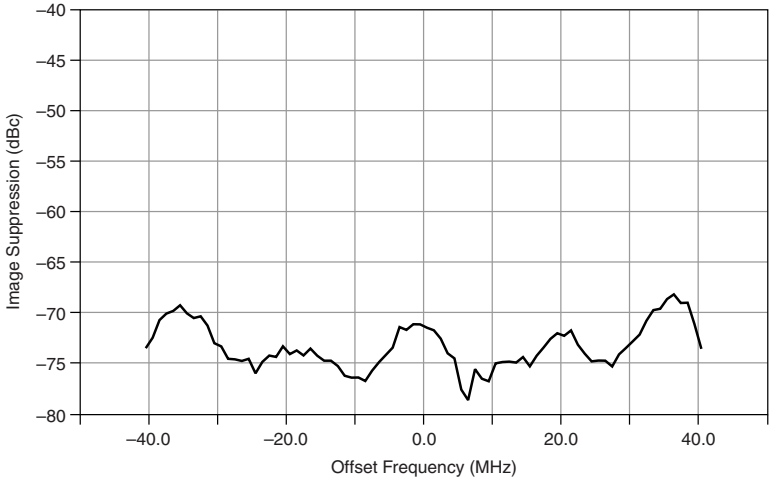
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## Image Suppression

**Table 37.** I/Q Output Image Suppression[55] (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.<br><br>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




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

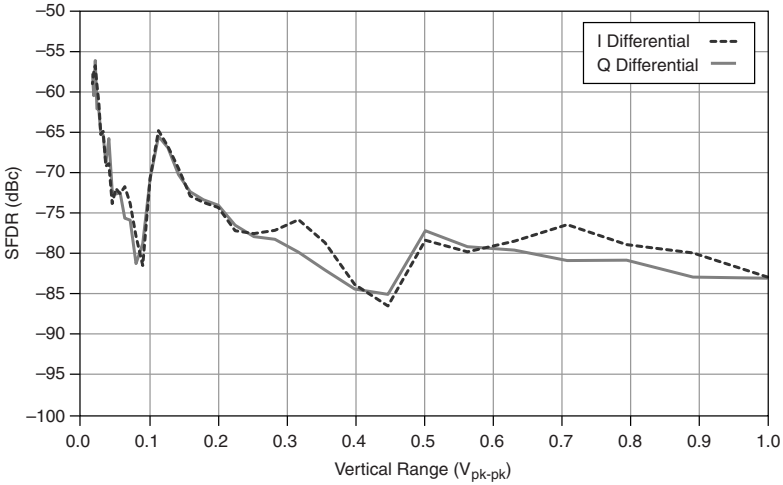


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# Spectral Characteristics

## SFDR

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




## SINAD

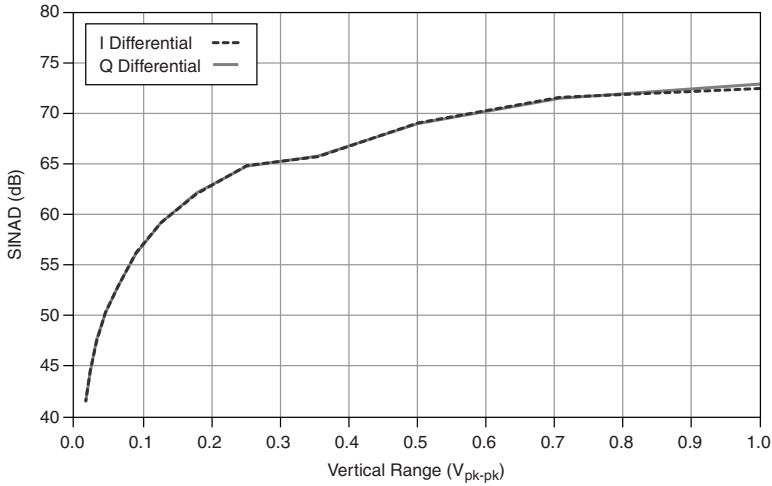
| I/Q output SINAD[56] (dB) | |
|---|---|
| 23 °C ± 5 °C | 66, typical |
| 0 °C to 55 °C | 64, typical |

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



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**Figure 32.** Measured I/Q Output SINAD[56]




## SNR

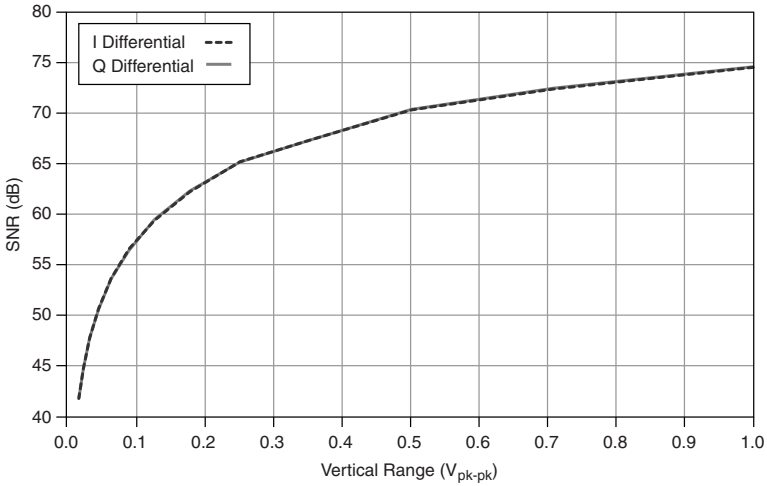
| I/Q output SNR[57] (dB) | |
|---|---|
| 23 °C ± 5 °C | 66, typical |
| 0 °C to 55 °C | 64, typical |

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



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**Figure 33.** Measured I/Q Output SNR[57]




## Average Noise Density

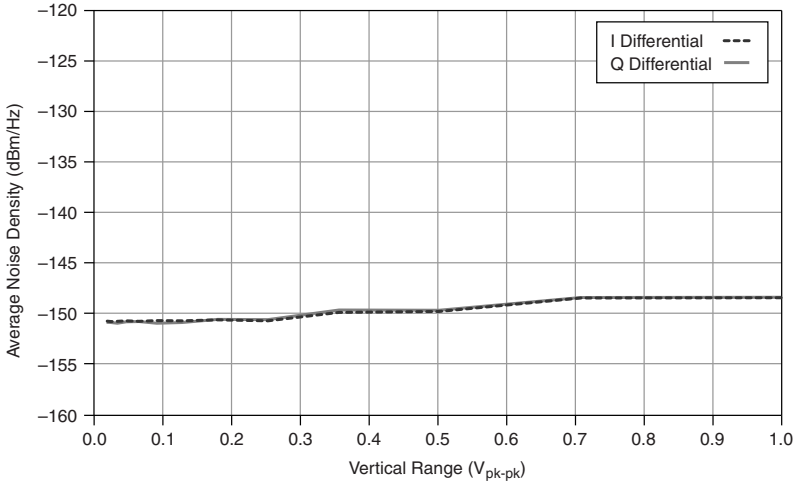
| I/Q output average noise density[58] (dBm/Hz) | |
|---|---|
| 23 °C ± 5 °C | -149, typical |
| 0 °C to 55 °C | -147, typical |

[58] Terminated into 50 Ω.



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**Figure 34.** Measured I/Q Output Noise Density[58]




## Harmonics

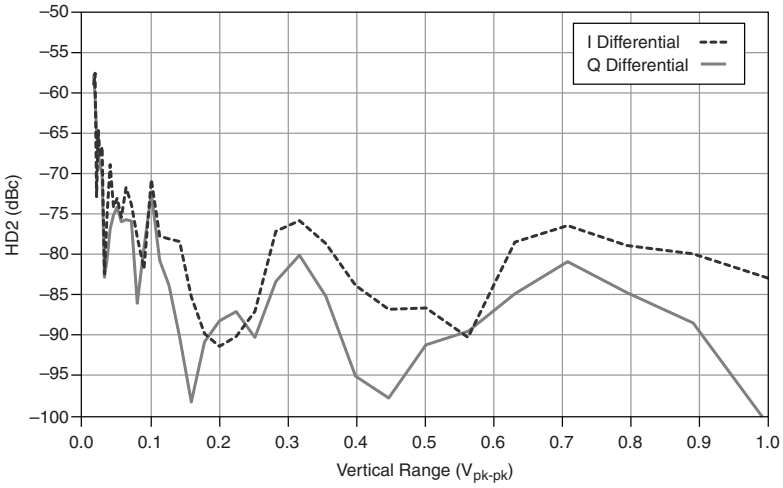
| I/Q output second harmonic[59] (dBc) | |
|---|---|
| 23 °C ± 5 °C | -75, typical |
| 0 °C to 55 °C | -73, typical |

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



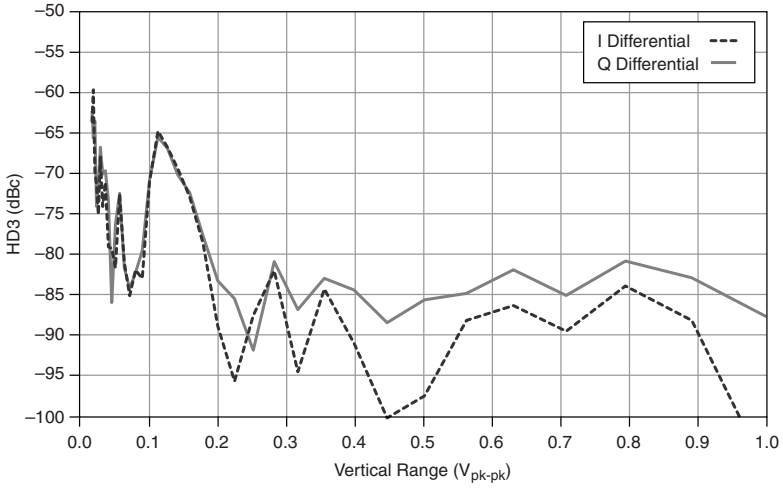
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**Figure 35.** Measured I/Q Output Second Harmonic[59]




| I/Q output third harmonic[59] (dBc) | |
|---|---|
| 23 °C ± 5 °C | -84, typical |
| 0 °C to 55 °C | -83, typical |

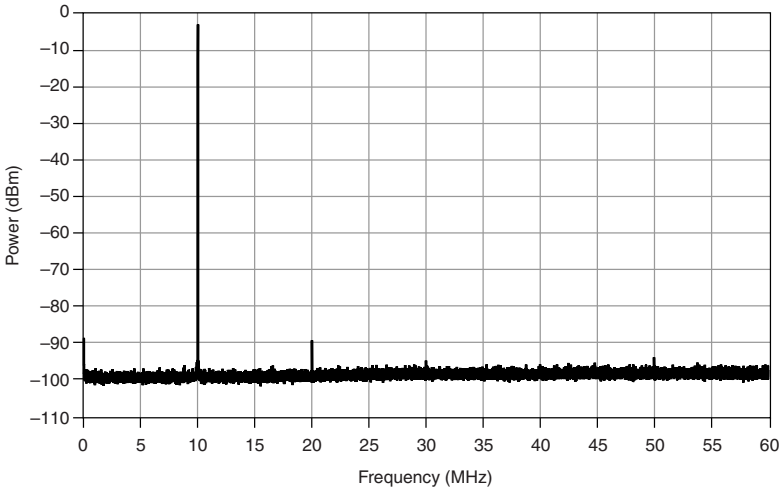
**Figure 36.** Measured I/Q Output Third Harmonic[59]






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**Figure 37.** Measured I/Q Output Single Tone Spectrum




## Third-Order Output Intermodulation

| I/Q third-order output intermodulation[60] ($IMD_3$) (dBc) | |
|---|---|
| 23 °C ± 5 °C | -80, typical |
| 0 °C to 55 °C | -75, typical |

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



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**Figure 38.** Measured I/Q Output $IMD_3$[60]

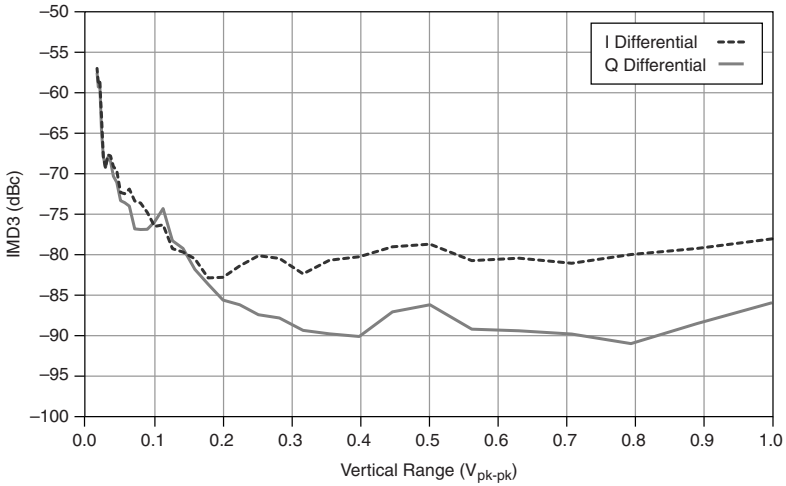
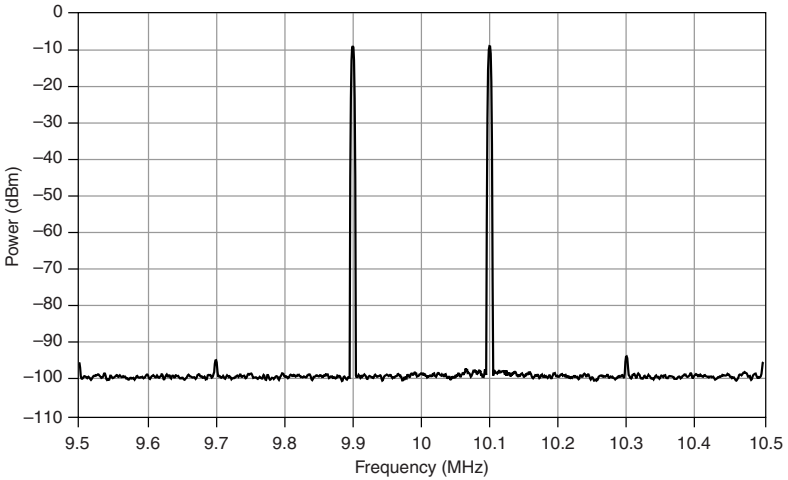



**Figure 39.** Measured I/Q Output Two-Tone Spectrum




## Second-Order Output Intermodulation

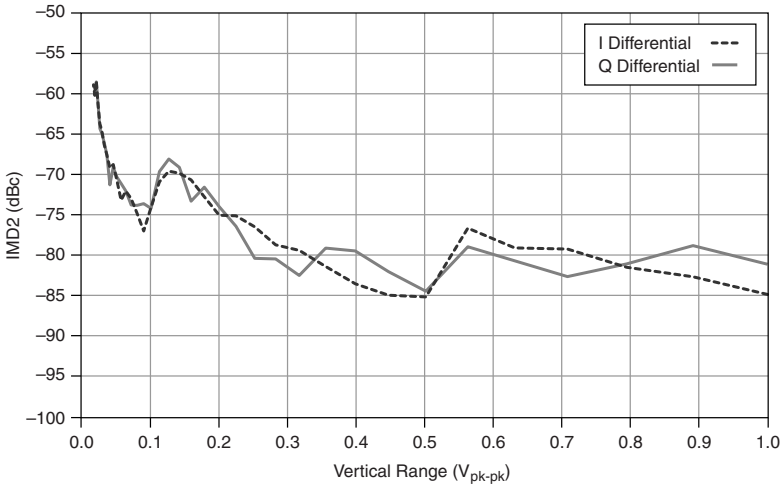
| I/Q second-order output intermodulation[61] ($IMD_2$) (dBc) | |
|---|---|
| 23 °C ± 5 °C | -80, typical |
| 0 °C to 55 °C | -75, typical |

[61] Generating -1 dBFS CW tones at 9.9 MHz and 10.1 MHz.



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**Figure 40.** I/Q Output $IMD_2$[61]




# Application-Specific Modulation Quality

Typical performance assumes the PXIe-5645 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[62] | -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. | | |

[62] 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.



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## 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[63] -48 EVM (rms) dB, typical

## LTE

**Table 41.** SC-FDMA[64] (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 |

[63] 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.

[64] Single channel uplink only.



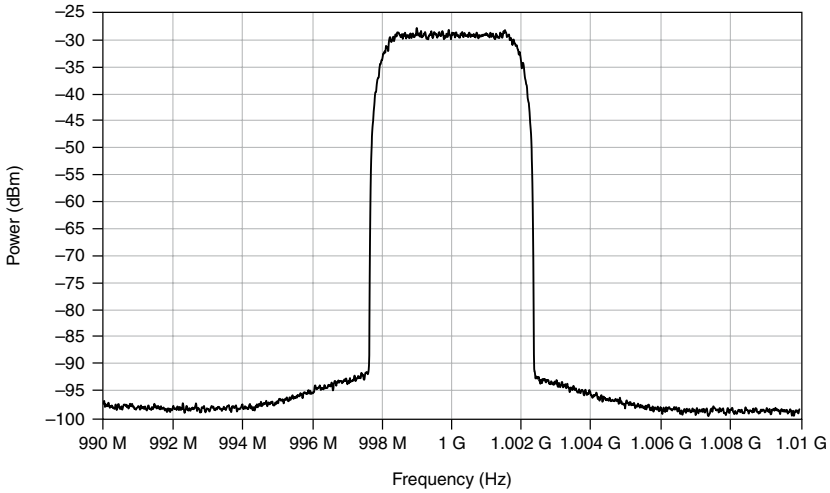
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**Table 41.** SC-FDMA[64] (Uplink FDD) EVM (rms) (dB), Typical (Continued)

| 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[65] (ACP)




# I/Q Baseband Application-Specific Modulation Quality

## WLAN 802.11ac

| | |
|---|---|
| OFDM[66] | -53 EVM (rms) dB, nominal |

## WLAN 802.11n

| | |
|---|---|
| OFDM[67] | -54 EVM (rms) dB, nominal |

64 Single channel uplink only.

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

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

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



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### WLAN 802.11a/g/j/p

| | |
|---|---|
| OFDM[68] | -58 EVM (rms) dB, nominal |

### WLAN 802.11g

| | |
|---|---|
| DSSS-OFDM[69] | -56 EVM (rms) dB, nominal |

### WLAN 802.11b/g

| | |
|---|---|
| DSSS[70] | -51 EVM (rms) dB, nominal |

### LTE

| | |
|---|---|
| SC-FDMA[71] (Uplink FDD) | -56 channel EVM (rms) dB, nominal |

## Baseband Characteristics

| | |
|---|---|
| Analog-to-digital converters (ADCs) | |
| Resolution | 16 bits |
| Sample rate[72] | 120 MS/s |
| I/Q data rate[73] | 1.84 kS/s to 120 MS/s |
| Digital-to-analog converters (DACs) | |
| Resolution | 16 bits |
| Sample rate[74] | 120 MS/s |
| I/Q data rate[75] | 1.84 kS/s to 120 MS/s |

## Onboard FPGA

| | |
|---|---|
| FPGA | Xilinx Virtex-6 LX195T |
| LUTs | 124,800 |

[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; 20 packets; 3/4 coding rate; 64 QAM.

[70] 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.

[71] 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.

[72] ADCs are dual-channel components with each channel assigned to I and Q, respectively.

[73] I/Q data rates lower than 120 MS/s are achieved using fractional decimation.

[74] 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.

[75] I/Q data rates lower than 120 MS/s are achieved using fractional interpolation.



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| | |
|---|---|
| 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[76] | +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). | |

[76] For modulated signals, peak instantaneous power not to exceed +36 dBm.



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# RF OUT

| | |
|---|---|
| Connector | SMA (female) |
| Output impedance | 50 Ω, nominal, AC coupled |
| Absolute maximum reverse power[77] | |
| <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[78] | 65 MHz to 6 GHz |
| Power | |
| LO OUT (RF IN 0) 65 MHz to 6 GHz | 0 dBm ±2 dB, typical |

[77] For modulated signals, peak instantaneous power not to exceed corresponding peak power of specified CW.

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



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| | |
|---|---|
| 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[79] | 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 |

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



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| | |
|---|---|
| Input type | Single-ended[80], 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[81], differential |
| Number of channels | 2 |

## REF IN

| | |
|---|---|
| Connector | SMA (female) |
| Frequency | 10 MHz |
| Tolerance[82] | $\pm 10 \times 10^{-6}$ |
| Amplitude | |
| Square | 0.7 $V_{pk-pk}$ to 5.0 $V_{pk-pk}$ into 50 Ω, typical |
| Sine[83] | 1.4 $V_{pk-pk}$ to 5.0 $V_{pk-pk}$ into 50 Ω, typical |
| Input impedance | 50 Ω, nominal |
| Coupling | AC |

## REF OUT

| | |
|---|---|
| Connector | SMA (female) |
| Frequency | |
| Reference Clock[84] | 10 MHz, nominal |
| Sample Clock | 120 MHz, nominal |
| Amplitude | 1.65 Vpk-pk into 50 Ω, nominal |

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



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| | |
|---|---|
| Output impedance | 50 Ω, nominal |
| Coupling | AC |

## PFI 0

| | |
|---|---|
| Connector | SMA (female) |
| Voltage levels[85] | |
| 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[86] | 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 |

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



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

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

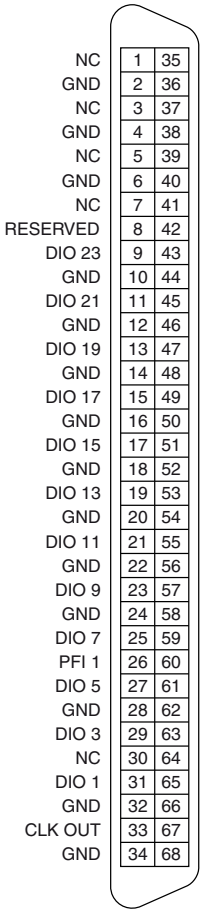
| | |
|---|---|
| Voltage levels[87] | |
| Absolute maximum input range | -0.5 V to 4.5 V |
| $V_{IL}$ | 0.8 V |
| $V_{IH}$ | 2.0 V |
| $V_{OL}$ | 0.2 V with 100 µA load |
| $V_{OH}$ | 2.9 V with 100 µA load |
| Input impedance | |
| DIO <23..0>, CLK IN | 10 kΩ, nominal |
| PFI 1, PFI 2 | 100 kΩ pull up, nominal |
| Output impedance | 50 Ω, nominal |
| Maximum DC drive strength | 12 mA |
| Minimum required direction change latency[88] | 48 ns + 1 clock cycle |
| Maximum toggle rate | 125 MHz, typical |

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



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**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 PXI Express backplane power connectors. | | |



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# 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*.

# Physical Characteristics

| | |
|---|---|
| PXIe-5645 module | 3U, four slot, PXI Express module<br>8.1 cm × 12.9 cm × 21.1 cm<br>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.) |



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# 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 $g_{rms}$ (Tested in accordance with IEC 60068-2-64.) |
| Nonoperating | 5 Hz to 500 Hz, 2.4 $g_{rms}$ (Tested in accordance with IEC 60068-2-64. 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 C22.2 No. 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.



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**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 CE

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

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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.

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