



# Low Noise Rail-to-Rail Differential ADC Driver

## AD8139

### FEATURES

- Fully differential**
- Low noise**
  - 2.25 nV/ $\sqrt{\text{Hz}}$
  - 2.1 pA/ $\sqrt{\text{Hz}}$
- Low harmonic distortion**
  - 98 dBc SFDR @ 1 MHz
  - 85 dBc SFDR @ 5 MHz
  - 72 dBc SFDR @ 20 MHz
- High speed**
  - 410 MHz, 3 dB BW (G = 1)
  - 800 V/ $\mu\text{s}$  slew rate
  - 45 ns settling time to 0.01%
- 69 dB output balance @ 1 MHz**
- 80 dB dc CMRR**
- Low offset:  $\pm 0.5$  mV max**
- Low input offset current: 0.5  $\mu\text{A}$  max**
- Differential input and output**
- Differential-to-differential or single-ended-to-differential operation**
- Rail-to-rail output**
- Adjustable output common-mode voltage**
- Wide supply voltage range: 5 V to 12 V**
- Available in small SOIC package**

### GENERAL DESCRIPTION

The AD8139 is an ultralow noise, high performance differential amplifier with rail-to-rail output. With its low noise, high SFDR, and wide bandwidth, it is an ideal choice for driving ADCs with resolutions to 18 bits. The AD8139 is easy to apply, and its internal common-mode feedback architecture allows its output common-mode voltage to be controlled by the voltage applied to one pin. The internal feedback loop also provides outstanding output balance as well as suppression of even-order harmonic distortion products. Fully differential and single-ended-to-differential gain configurations are easily realized by the AD8139. Simple external feedback networks consisting of a total of four resistors determine the amplifier's closed-loop gain.

The AD8139 is manufactured on ADI's proprietary second generation XFCB process, enabling it to achieve low levels of distortion with input voltage noise of only 1.85 nV/ $\sqrt{\text{Hz}}$ .

### APPLICATIONS

- ADC drivers to 18 bits
- Single-ended-to-differential converters
- Differential filters
- Level shifters
- Differential PCB board drivers
- Differential cable drivers

### FUNCTIONAL BLOCK DIAGRAM

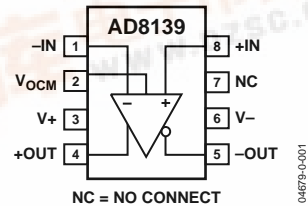


Figure 1.

The AD8139 is available in an 8-lead SOIC package with an exposed paddle (EP) on the underside of its body and a 3 mm  $\times$  3 mm LFCSP. It is rated to operate over the temperature range of  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

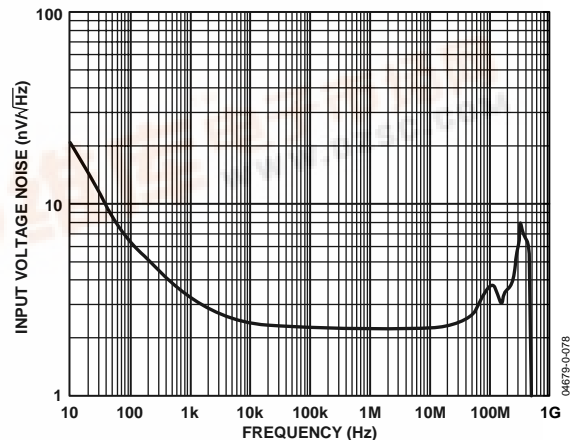


Figure 2. Input Voltage Noise vs. Frequency



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**REVISION HISTORY**

**8/04—Data Sheet Changed from a Rev. 0 to Rev. A.**

|  |           |
|--|-----------|
| Added 8-Lead LFCSP.....  | Universal |
| Changes to General Description .....   | 1         |
| Changes to Figure 2.....   | 1         |
| Changes to $V_S = \pm 5\text{ V}, V_{OCM} = 0\text{ V}$ Specifications ..... | 3         |
| Changes to $V_S = 5\text{ V}, V_{OCM} = 2.5\text{ V}$ Specifications.....    | 5         |
| Changes to Table 4.....  | 7         |
| Changes to Maximum Power Dissipation Section.....                            | 7         |
| Changes to Figure 26 and Figure 29.....                                      | 12        |
| Inserted Figure 39 and Figure 42.....  | 14        |
| Changes to Figure 45 to Figure 47 .....                                      | 15        |
| Inserted Figure 48.....  | 15        |
| Changes to Figure 52 and Figure 53.....                                      | 16        |
| Changes to Figure 55 and Figure 56.....                                      | 17        |
| Changes to Table 6.....  | 19        |
| Changes to Voltage Gain Section.....   | 19        |
| Changes to Driving a Capacitive Load Section .....                           | 22        |
| Changes to Ordering Guide .....  | 24        |
| Updated Outline Dimensions .....   | 24        |

**5/04—Revision 0: Initial Version**

## $V_S = \pm 5\text{ V}$ , $V_{OCM} = 0\text{ V}$ SPECIFICATIONS

@ 25°C, Diff. Gain = 1,  $R_{L, dm} = 1\text{ k}\Omega$ ,  $R_F = R_G = 200\ \Omega$ , unless otherwise noted.  $T_{MIN}$  to  $T_{MAX} = -40^\circ\text{C}$  to  $+125^\circ\text{C}$ .

Table 1.

| Parameter                            | Conditions   | Min           | Typ       | Max           | Unit                         |
|--------------------------------------|--|---------------|-----------|---------------|------------------------------|
| DIFFERENTIAL INPUT PERFORMANCE       |  |               |           |               |                              |
| DYNAMIC PERFORMANCE                  |  |               |           |               |                              |
| -3 dB Small Signal Bandwidth         | $V_{O, dm} = 0.1\text{ V p-p}$   | 340           | 410       |               | MHz                          |
| -3 dB Large Signal Bandwidth         | $V_{O, dm} = 2\text{ V p-p}$   | 210           | 240       |               | MHz                          |
| Bandwidth for 0.1 dB Flatness        | $V_{O, dm} = 0.1\text{ V p-p}$   |               | 45        |               | MHz                          |
| Slew Rate                            | $V_{O, dm} = 2\text{ V Step}$  |               | 800       |               | V/ $\mu\text{s}$             |
| Settling Time to 0.01%               | $V_{O, dm} = 2\text{ V Step}$ , $C_F = 2\text{ pF}$  |               | 45        |               | ns                           |
| Overdrive Recovery Time              | $G = 2$ , $V_{IN, dm} = 12\text{ V p-p Triangle Wave}$   |               | 30        |               | ns                           |
| NOISE/HARMONIC PERFORMANCE           |  |               |           |               |                              |
| SFDR                                 | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 1\text{ MHz}$  |               | 98        |               | dB                           |
|                                      | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 5\text{ MHz}$  |               | 85        |               | dB                           |
|                                      | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 20\text{ MHz}$   |               | 72        |               | dB                           |
| Third-Order IMD                      | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 10.05\text{ MHz} \pm 0.05\text{ MHz}$                      |               | -90       |               | dBc                          |
| Input Voltage Noise                  | $f = 100\text{ KHz}$   |               | 2.25      |               | nV/ $\sqrt{\text{Hz}}$       |
| Input Current Noise                  | $f = 100\text{ KHz}$   |               | 2.1       |               | pA/ $\sqrt{\text{Hz}}$       |
| DC PERFORMANCE                       |  |               |           |               |                              |
| Input Offset Voltage                 | $V_{IP} = V_{IN} = V_{OCM} = 0\text{ V}$   | -500          | $\pm 150$ | +500          | $\mu\text{V}$                |
| Input Offset Voltage Drift           | $T_{MIN}$ to $T_{MAX}$   |               | 1.25      |               | $\mu\text{V}/^\circ\text{C}$ |
| Input Bias Current                   | $T_{MIN}$ to $T_{MAX}$   |               | 2.25      | 8.0           | $\mu\text{A}$                |
| Input Offset Current                 |  |               | 0.12      | 0.5           | $\mu\text{A}$                |
| Open-Loop Gain                       |  |               | 114       |               | dB                           |
| INPUT CHARACTERISTICS                |  |               |           |               |                              |
| Input Common-Mode Voltage Range      |  | -4            |           | +4            | V                            |
| Input Resistance                     | Differential   |               | 600       |               | k $\Omega$                   |
|                                      | Common Mode  |               | 1.5       |               | M $\Omega$                   |
| Input Capacitance                    | Common Mode  |               | 1.2       |               | pF                           |
| CMRR                                 | $\Delta V_{ICM} = \pm 1\text{ V dc}$ , $R_F = R_G = 10\text{ k}\Omega$                           | 80            | 84        |               | dB                           |
| OUTPUT CHARACTERISTICS               |  |               |           |               |                              |
| Output Voltage Swing                 | Each Single-Ended Output, $R_F = R_G = 10\text{ k}\Omega$  | $-V_S + 0.20$ |           | $+V_S - 0.20$ | V                            |
|                                      | Each Single-Ended Output,<br>$R_{L, dm} = \text{Open Circuit}$ , $R_F = R_G = 10\text{ k}\Omega$ | $-V_S + 0.15$ |           | $+V_S - 0.15$ | V                            |
| Output Current                       | Each Single-Ended Output   |               | 100       |               | mA                           |
| Output Balance Error                 | $f = 1\text{ MHz}$   |               | -69       |               | dB                           |
| $V_{OCM}$ to $V_{O, cm}$ PERFORMANCE |  |               |           |               |                              |
| $V_{OCM}$ DYNAMIC PERFORMANCE        |  |               |           |               |                              |
| -3 dB Bandwidth                      | $V_{O, cm} = 0.1\text{ V p-p}$   |               | 515       |               | MHz                          |
| Slew Rate                            | $V_{O, cm} = 2\text{ V p-p}$   |               | 250       |               | V/ $\mu\text{s}$             |
| Gain                                 |  | 0.999         | 1.000     | 1.001         | V/V                          |
| $V_{OCM}$ INPUT CHARACTERISTICS      |  |               |           |               |                              |
| Input Voltage Range                  |  | -3.8          |           | +3.8          | V                            |
| Input Resistance                     |  |               | 3.5       |               | M $\Omega$                   |
| Input Offset Voltage                 | $V_{OS, cm} = V_{O, cm} - V_{OCM}$ ; $V_{IP} = V_{IN} = V_{OCM} = 0\text{ V}$                    | -900          | $\pm 300$ | +900          | $\mu\text{V}$                |
| Input Voltage Noise                  | $f = 100\text{ kHz}$   |               | 3.5       |               | nV/ $\sqrt{\text{Hz}}$       |
| Input Bias Current                   |  |               | 1.3       | 4.5           | $\mu\text{A}$                |
| CMRR                                 | $\Delta V_{OCM}/\Delta V_{O, dm}$ , $\Delta V_{OCM} = \pm 1\text{ V}$                            | 74            | 88        |               | dB                           |

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| Parameter                   | Conditions                | Min | Typ  | Max  | Unit |
|-----------------------------|---------------------------|-----|------|------|------|
| POWER SUPPLY                |                           |     |      |      |      |
| Operating Range             |                           | 4.5 |      | ±6   | V    |
| Quiescent Current           |                           |     | 24.5 | 25.5 | mA   |
| +PSRR                       | Change in $+V_S = \pm 1V$ | 95  | 112  |      | dB   |
| -PSRR                       | Change in $-V_S = \pm 1V$ | 95  | 109  |      | dB   |
| OPERATING TEMPERATURE RANGE |                           | -40 |      | +125 | °C   |

## $V_S = 5\text{ V}$ , $V_{OCM} = 2.5\text{ V}$ SPECIFICATIONS

@ 25°C, Diff. Gain = 1,  $R_{L, dm} = 1\text{ k}\Omega$ ,  $R_F = R_G = 200\ \Omega$ , unless otherwise noted.  $T_{MIN}$  to  $T_{MAX} = -40^\circ\text{C}$  to  $+125^\circ\text{C}$ .

Table 2.

| Parameter                            | Conditions   | Min           | Typ        | Max           | Unit                         |
|--------------------------------------|--|---------------|------------|---------------|------------------------------|
| DIFFERENTIAL INPUT PERFORMANCE       |  |               |            |               |                              |
| DYNAMIC PERFORMANCE                  |  |               |            |               |                              |
| -3 dB Small Signal Bandwidth         | $V_{O, dm} = 0.1\text{ V p-p}$   | 330           | 385        |               | MHz                          |
| -3 dB Large Signal Bandwidth         | $V_{O, dm} = 2\text{ V p-p}$   | 135           | 165        |               | MHz                          |
| Bandwidth for 0.1 dB Flatness        | $V_{O, dm} = 0.1\text{ V p-p}$   |               | 34         |               | MHz                          |
| Slew Rate                            | $V_{O, dm} = 2\text{ V Step}$  |               | 540        |               | V/ $\mu\text{s}$             |
| Settling Time to 0.01%               | $V_{O, dm} = 2\text{ V Step}$  |               | 55         |               | ns                           |
| Overdrive Recovery Time              | $G = 2$ , $V_{IN, dm} = 7\text{ V p-p Triangle Wave}$  |               | 35         |               | ns                           |
| NOISE/HARMONIC PERFORMANCE           |  |               |            |               |                              |
| SFDR                                 | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 1\text{ MHz}$  |               | 99         |               | dB                           |
|                                      | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 5\text{ MHz}$ , ( $R_L = 800\ \Omega$ )                    |               | 87         |               | dB                           |
|                                      | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 20\text{ MHz}$ , ( $R_L = 800\ \Omega$ )                   |               | 75         |               | dB                           |
| Third-Order IMD                      | $V_{O, dm} = 2\text{ V p-p}$ , $f_c = 10.05\text{ MHz} \pm 0.05\text{ MHz}$                      |               | -87        |               | dBc                          |
| Input Voltage Noise                  | $f = 100\text{ kHz}$   |               | 2.25       |               | nV/ $\sqrt{\text{Hz}}$       |
| Input Current Noise                  | $f = 100\text{ kHz}$   |               | 2.1        |               | pA/ $\sqrt{\text{Hz}}$       |
| DC PERFORMANCE                       |  |               |            |               |                              |
| Input Offset Voltage                 | $V_{IP} = V_{IN} = V_{OCM} = 0\text{ V}$   | -500          | $\pm 150$  | +500          | $\mu\text{V}$                |
| Input Offset Voltage Drift           | $T_{MIN}$ to $T_{MAX}$   |               | 1.25       |               | $\mu\text{V}/^\circ\text{C}$ |
| Input Bias Current                   | $T_{MIN}$ to $T_{MAX}$   |               | 2.2        | 7.5           | $\mu\text{A}$                |
| Input Offset Current                 |  |               | 0.13       | 0.5           | $\mu\text{A}$                |
| Open-Loop Gain                       |  |               | 112        |               | dB                           |
| INPUT CHARACTERISTICS                |  |               |            |               |                              |
| Input Common-Mode Voltage Range      |  | 1             |            | 4             | V                            |
| Input Resistance                     | Differential   |               | 600        |               | K $\Omega$                   |
|                                      | Common-Mode  |               | 1.5        |               | M $\Omega$                   |
| Input Capacitance                    | Common-Mode  |               | 1.2        |               | pF                           |
| CMRR                                 | $\Delta V_{ICM} = \pm 1\text{ V dc}$ , $R_F = R_G = 10\text{ k}\Omega$                           | 75            | 79         |               | dB                           |
| OUTPUT CHARACTERISTICS               |  |               |            |               |                              |
| Output Voltage Swing                 | Each Single-Ended Output, $R_F = R_G = 10\text{ k}\Omega$  | $-V_S + 0.15$ |            | $+V_S - 0.15$ | V                            |
|                                      | Each Single-Ended Output,<br>$R_{L, dm} = \text{Open Circuit}$ , $R_F = R_G = 10\text{ k}\Omega$ | $-V_S + 0.10$ |            | $+V_S - 0.10$ | V                            |
| Output Current                       | Each Single-Ended Output   |               | 80         |               | mA                           |
| Output Balance Error                 | $f = 1\text{ MHz}$   |               | -70        |               | dB                           |
| $V_{OCM}$ to $V_{O, cm}$ PERFORMANCE |  |               |            |               |                              |
| $V_{OCM}$ DYNAMIC PERFORMANCE        |  |               |            |               |                              |
| -3 dB Bandwidth                      | $V_{O, cm} = 0.1\text{ V p-p}$   |               | 440        |               | MHz                          |
| Slew Rate                            | $V_{O, cm} = 2\text{ V p-p}$   |               | 150        |               | V/ $\mu\text{s}$             |
| Gain                                 |  | 0.999         | 1.000      | 1.001         | V/V                          |
| $V_{OCM}$ INPUT CHARACTERISTICS      |  |               |            |               |                              |
| Input Voltage Range                  |  | 1.0           |            | 3.8           | V                            |
| Input Resistance                     |  |               | 3.5        |               | M $\Omega$                   |
| Input Offset Voltage                 | $V_{OS, cm} = V_{O, cm} - V_{OCM}$ ; $V_{IP} = V_{IN} = V_{OCM} = 2.5\text{ V}$                  | -1.0          | $\pm 0.45$ | +1.0          | mV                           |
| Input Voltage Noise                  | $f = 100\text{ KHz}$   |               | 3.5        |               | nV/ $\sqrt{\text{Hz}}$       |
| Input Bias Current                   |  |               | 1.3        | 4.2           | $\mu\text{A}$                |
| CMRR                                 | $\Delta V_{OCM}/\Delta V_{O(dm)}$ , $\Delta V_{OCM} = \pm 1\text{ V}$                            | 67            | 79         |               | dB                           |

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| Parameter                   | Conditions                 | Min  | Typ  | Max  | Unit |
|-----------------------------|----------------------------|------|------|------|------|
| POWER SUPPLY                |                            |      |      |      |      |
| Operating Range             |                            | +4.5 |      | ±6   | V    |
| Quiescent Current           |                            |      | 21.5 | 22.5 | mA   |
| +PSRR                       | Change in $+V_s = \pm 1$ V | 86   | 97   |      | dB   |
| -PSRR                       | Change in $-V_s = \pm 1$ V | 92   | 105  |      | dB   |
| OPERATING TEMPERATURE RANGE |                            | -40  |      | +125 | °C   |

## ABSOLUTE MAXIMUM RATINGS

Table 3.

| Parameter                                    | Rating          |
|--|-----------------|
| Supply Voltage                               | 12 V            |
| $V_{OCM}$                                    | $\pm V_s$       |
| Power Dissipation                            | See Figure 3    |
| Input Common-Mode Voltage                    | $\pm V_s$       |
| Storage Temperature                          | -65°C to +125°C |
| Operating Temperature Range                  | -40°C to +125°C |
| Lead Temperature Range<br>(Soldering 10 sec) | 300°C           |
| Junction Temperature                         | 150°C           |

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

### THERMAL RESISTANCE

$\theta_{JA}$  is specified for the worst-case conditions, i.e.,  $\theta_{JA}$  is specified for device soldered in circuit board for surface-mount packages.

Table 4. Thermal Resistance

| Package Type           | $\theta_{JA}$ | Unit |
|------------------------|---------------|------|
| SOIC-8 with EP/4-Layer | 70            | °C/W |
| LFCSP/4-Layer          | 70            | °C/W |

### Maximum Power Dissipation

The maximum safe power dissipation in the AD8139 package is limited by the associated rise in junction temperature ( $T_J$ ) on the die. At approximately 150°C, which is the glass transition temperature, the plastic will change its properties. Even temporarily exceeding this temperature limit may change the stresses that the package exerts on the die, permanently shifting the parametric performance of the AD8139. Exceeding a junction temperature of 175°C for an extended period of time can result in changes in the silicon devices potentially causing failure.

### ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

The power dissipated in the package ( $P_D$ ) is the sum of the quiescent power dissipation and the power dissipated in the package due to the load drive for all outputs. The quiescent power is the voltage between the supply pins ( $V_s$ ) times the quiescent current ( $I_s$ ). The load current consists of differential and common-mode currents flowing to the load, as well as currents flowing through the external feedback networks and the internal common-mode feedback loop. The internal resistor tap used in the common-mode feedback loop places a 1 k $\Omega$  differential load on the output. RMS output voltages should be considered when dealing with ac signals.

Airflow reduces  $\theta_{JA}$ . Also, more metal directly in contact with the package leads from metal traces, through holes, ground, and power planes will reduce the  $\theta_{JA}$ .

Figure 3 shows the maximum safe power dissipation in the package versus the ambient temperature for the exposed paddle (EP) SOIC-8 ( $\theta_{JA} = 70^\circ\text{C}/\text{W}$ ) package and LFCSP ( $\theta_{JA} = 70^\circ\text{C}/\text{W}$ ) on a JEDEC standard 4-layer board.  $\theta_{JA}$  values are approximations.

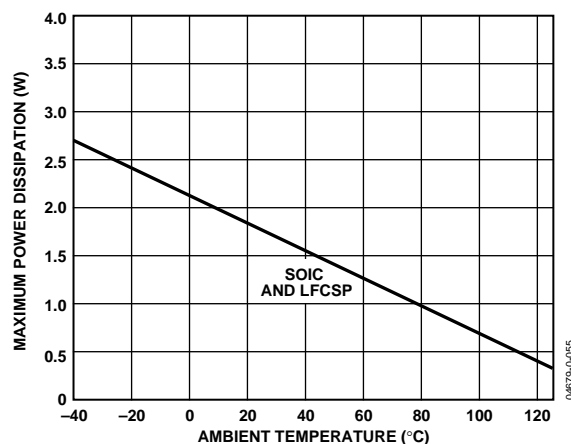


Figure 3. Maximum Power Dissipation vs. Temperature for a 4-Layer Board



# AD8139

## PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

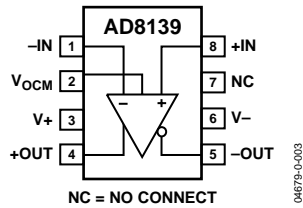


Figure 4. Pin Configuration

Table 5. Pin Function Descriptions

| Pin No. | Mnemonic         | Description  |
|---------|------------------|--|
| 1       | -IN              | Inverting Input.   |
| 2       | V <sub>OCM</sub> | An internal feedback loop drives the output common-mode voltage to be equal to the voltage applied to the V <sub>OCM</sub> pin, provided the amplifier's operation remains linear. |
| 3       | V+               | Positive Power Supply Voltage.   |
| 4       | +OUT             | Positive Side of the Differential Output.  |
| 5       | -OUT             | Negative Side of the Differential Output.  |
| 6       | V-               | Negative Power Supply Voltage.   |
| 7       | NC               | No Internal Connection.  |
| 8       | +IN              | Noninverting Input.  |

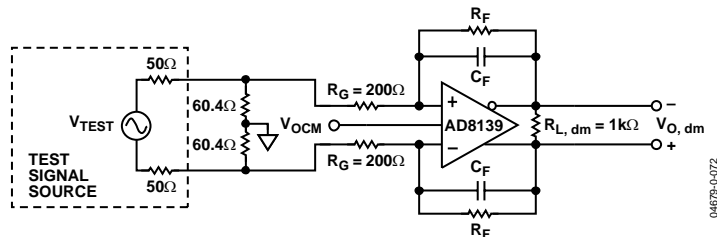


Figure 5. Basic Test Circuit

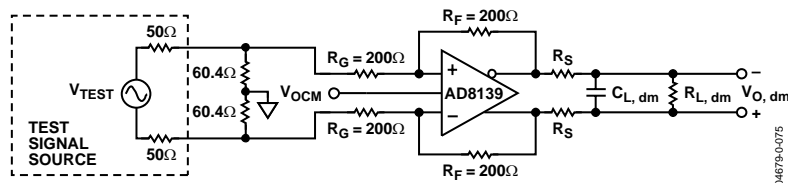


Figure 6. Capacitive Load Test Circuit,  $G = +1$



## TYPICAL PERFORMANCE CHARACTERISTICS

Unless otherwise noted, Diff. Gain = +1,  $R_G = R_F = 200\ \Omega$ ,  $R_{L, dm} = 1\ \text{k}\Omega$ ,  $V_S = \pm 5\ \text{V}$ ,  $T_A = 25^\circ\text{C}$ ,  $V_{OCM} = 0\ \text{V}$ . Refer to the basic test circuit in Figure 5 for the definition of terms.

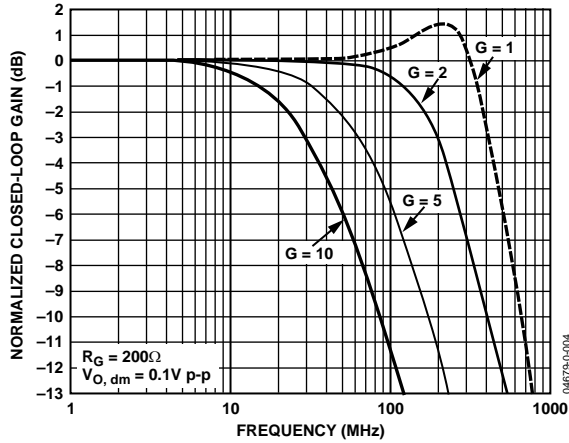


Figure 7. Small Signal Frequency Response for Various Gains

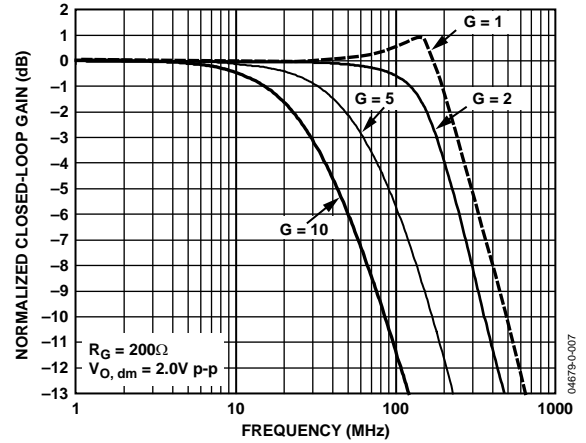


Figure 10. Large Signal Frequency Response for Various Gains

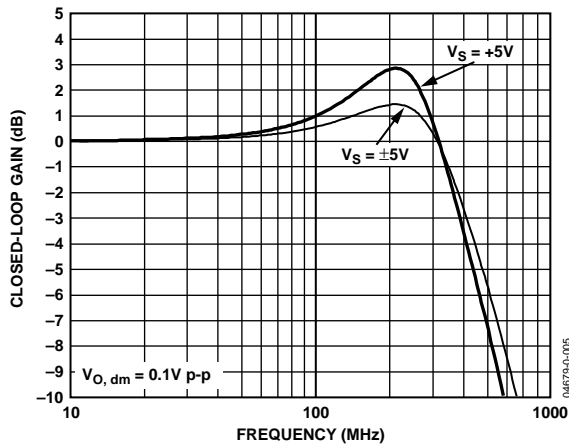


Figure 8. Small Signal Frequency Response for Various Power Supplies

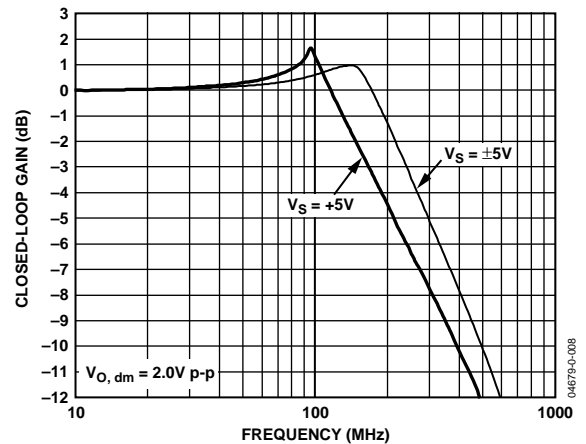


Figure 11. Large Signal Frequency Response for Various Power Supplies

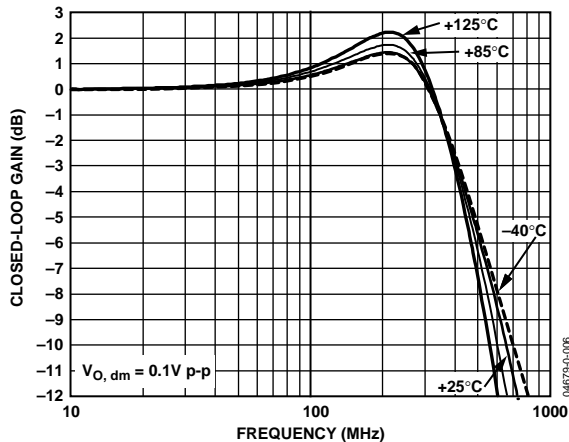


Figure 9. Small Signal Frequency Response at Various Temperatures

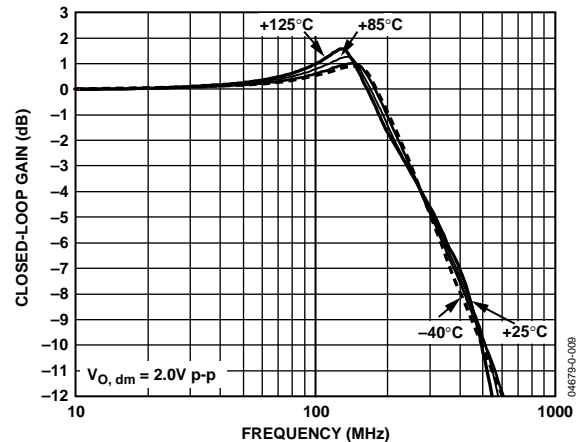


Figure 12. Large Signal Frequency Response at Various Temperatures

# AD8139

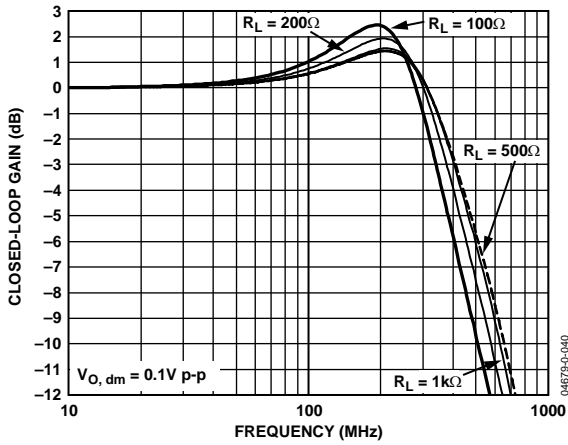


Figure 13. Small Signal Frequency Response for Various Loads

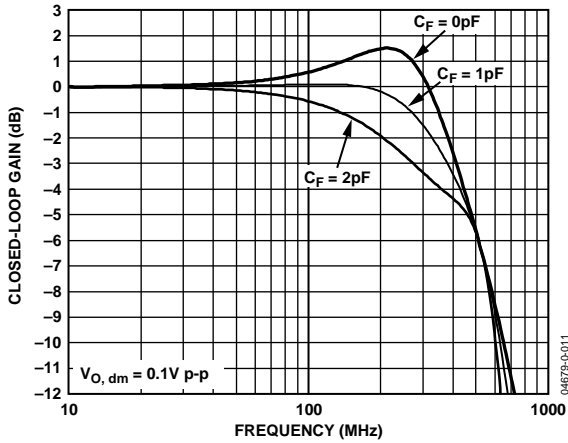


Figure 14. Small Signal Frequency Response for Various  $C_F$

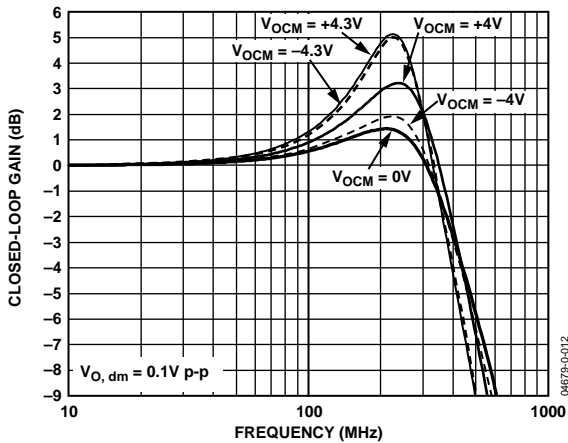


Figure 15. Small Signal Frequency Response at Various  $V_{OCM}$

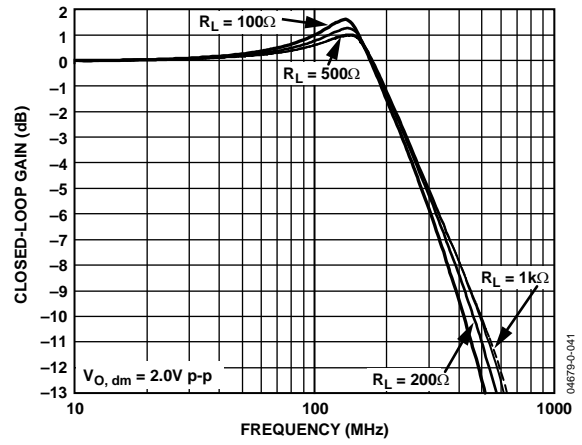


Figure 16. Large Signal Frequency Response for Various Loads

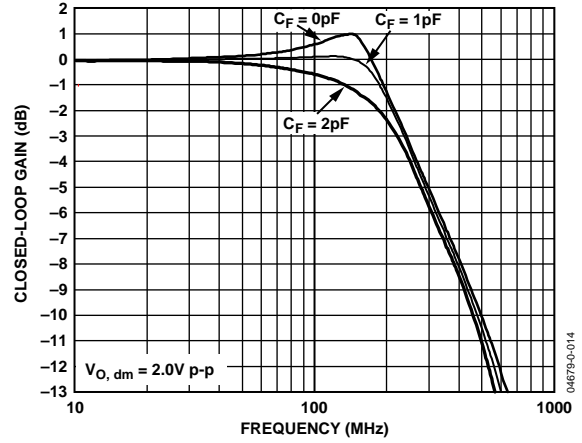


Figure 17. Large Signal Frequency Response for Various  $C_F$

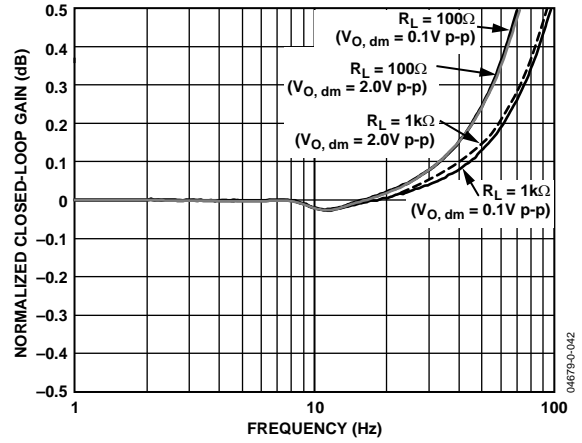


Figure 18. 0.1 dB Flatness for Various Loads and Output Amplitudes

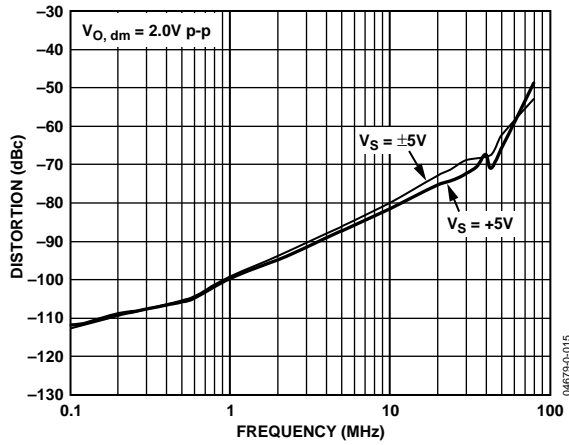


Figure 19. Second Harmonic Distortion vs. Frequency and Supply Voltage

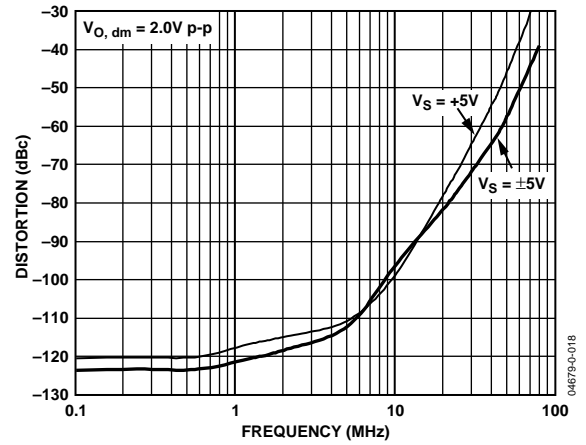


Figure 22. Third Harmonic Distortion vs. Frequency and Supply Voltage

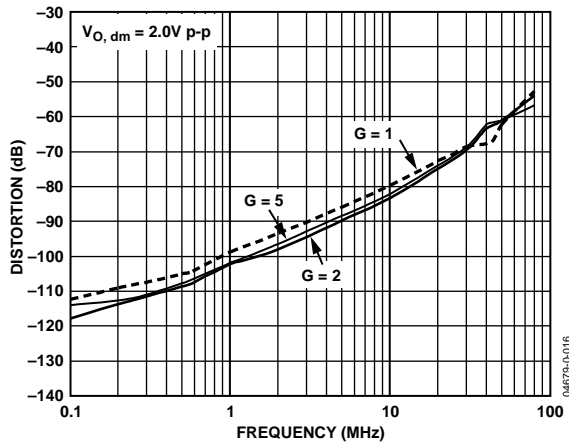


Figure 20. Second Harmonic Distortion vs. Frequency and Gain

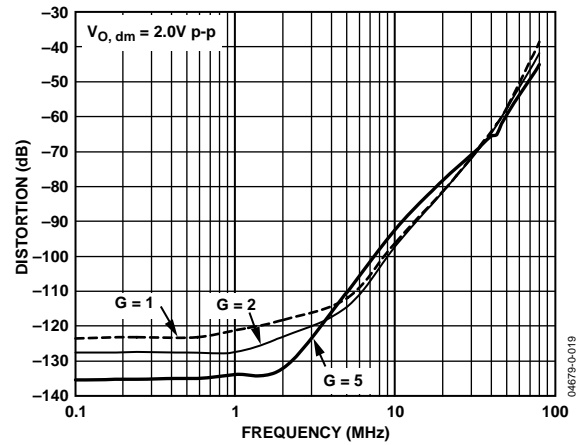


Figure 23. Third Harmonic Distortion vs. Frequency and Gain

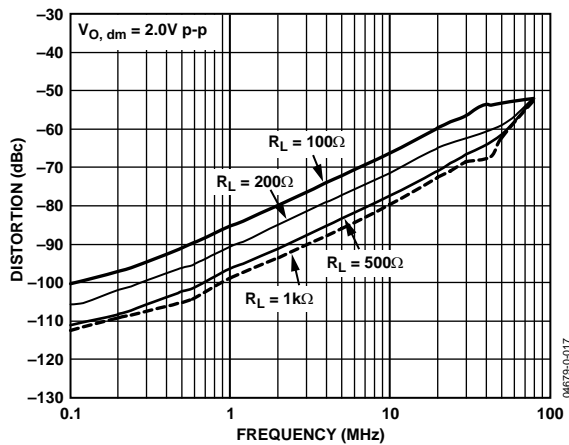


Figure 21. Second Harmonic Distortion vs. Frequency and Load

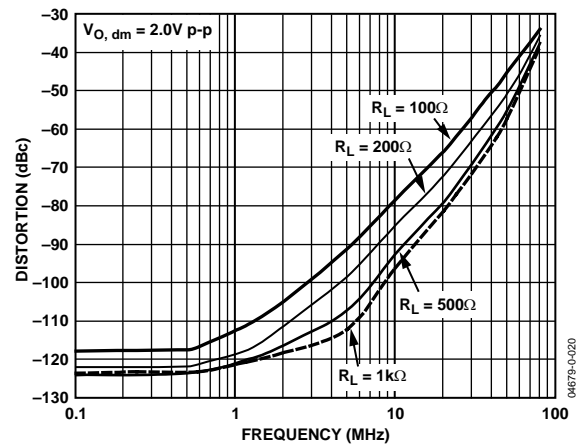


Figure 24. Third Harmonic Distortion vs. Frequency and Load

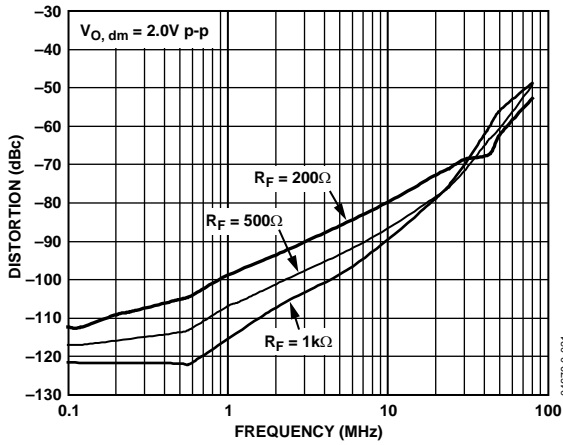


Figure 25. Second Harmonic Distortion vs. Frequency and  $R_F$

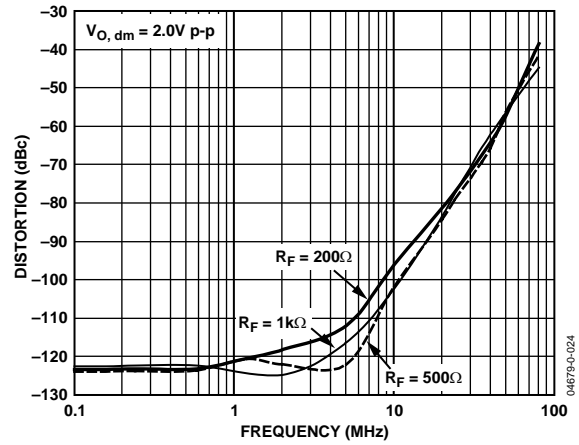


Figure 28. Third Harmonic Distortion vs. Frequency and  $R_F$

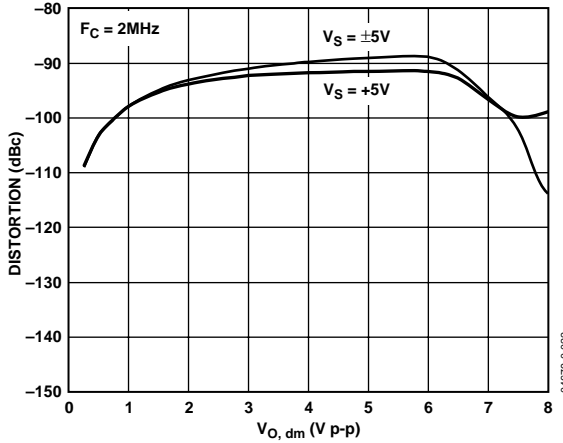


Figure 26. Second Harmonic Distortion vs. Output Amplitude

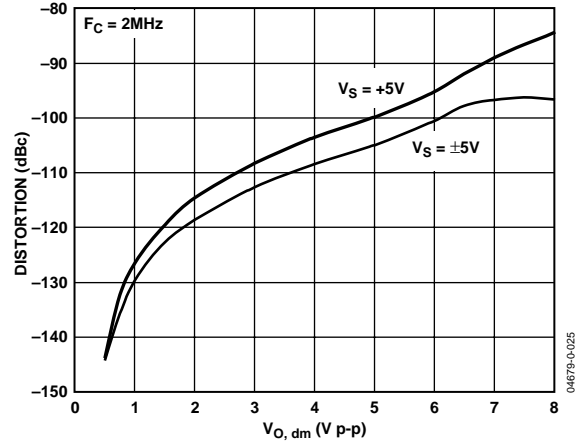


Figure 29. Third Harmonic Distortion vs. Output Amplitude

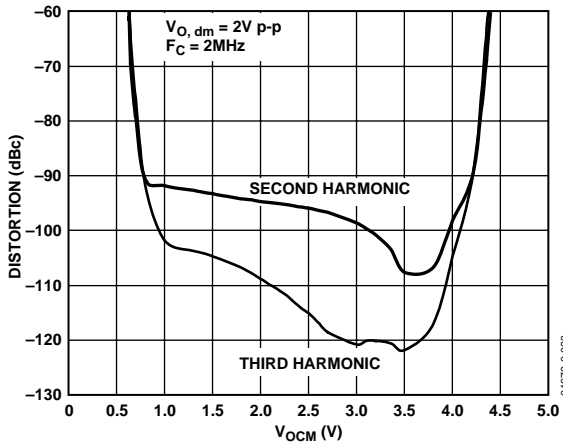


Figure 27. Harmonic Distortion vs.  $V_{OCM}$ ,  $V_S = +5V$

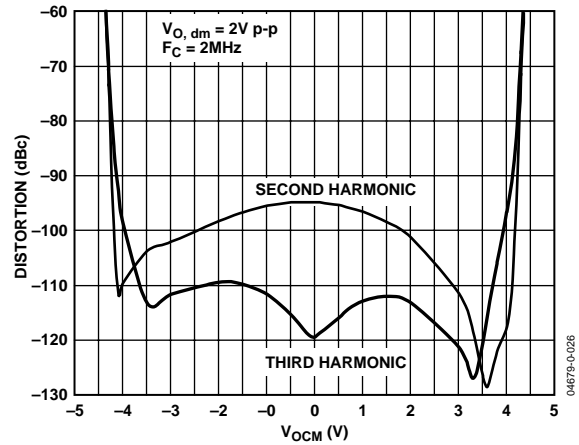


Figure 30. Harmonic Distortion vs.  $V_{OCM}$ ,  $V_S = \pm 5V$

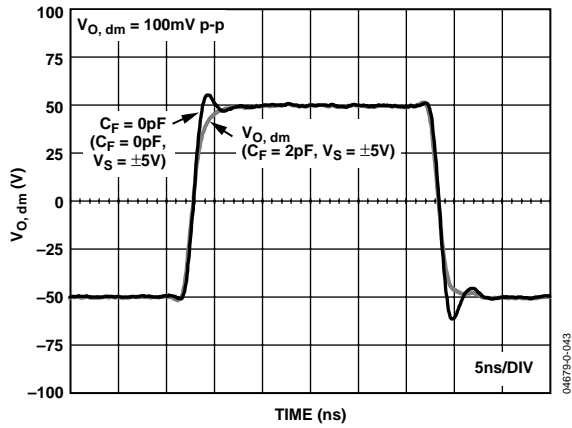


Figure 31. Small Signal Transient Response for Various  $C_f$

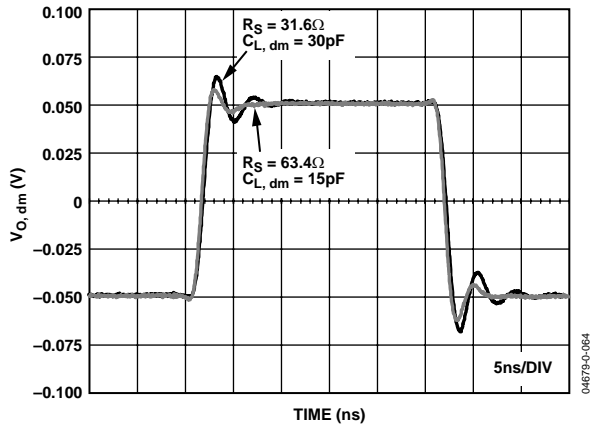


Figure 32. Small Signal Transient Response for Capacitive Loads

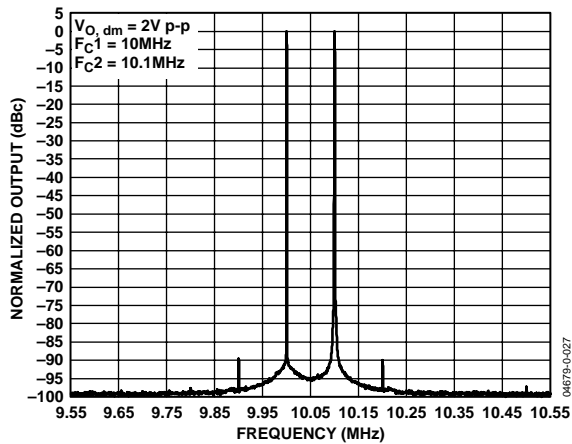


Figure 33. Intermodulation Distortion

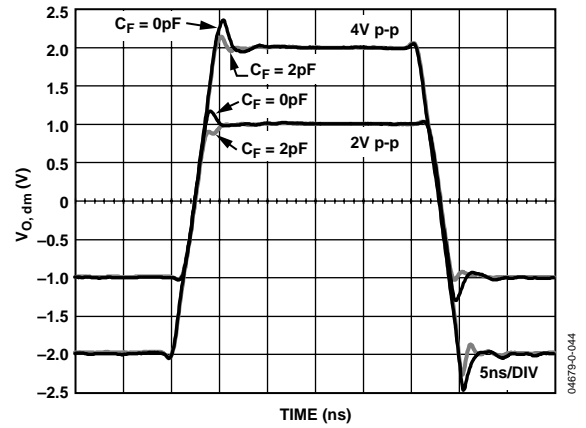


Figure 34. Large Signal Transient Response For  $C_f$

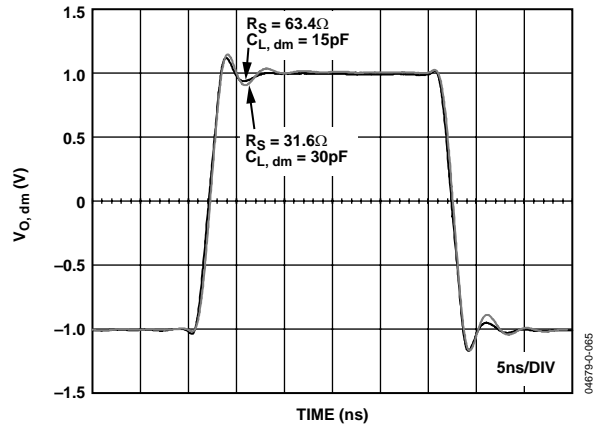


Figure 35. Large Signal Transient Response for Capacitive Loads

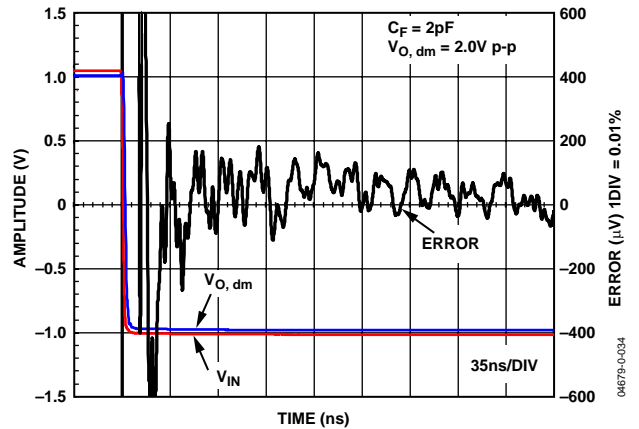


Figure 36. Settling Time (0.01%)

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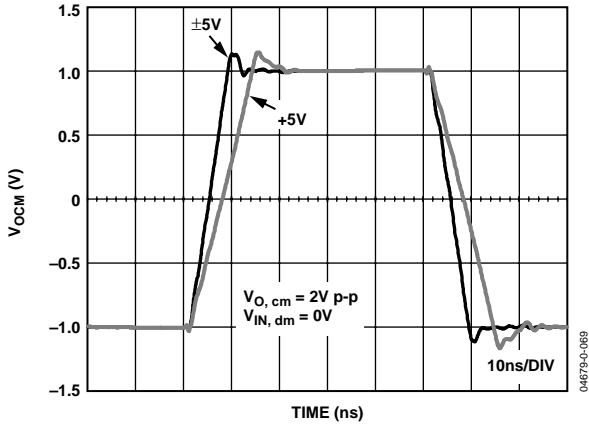


Figure 37.  $V_{OCM}$  Large Signal Transient Response

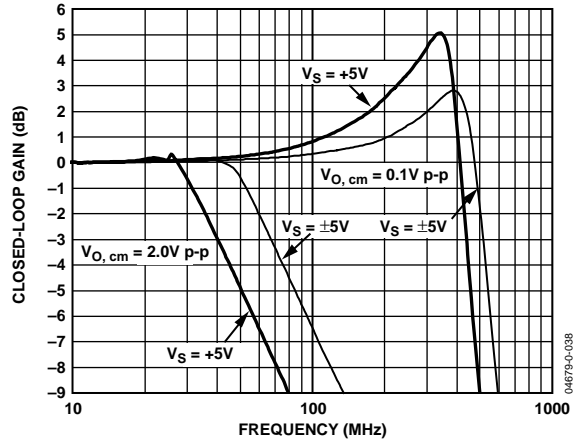


Figure 40.  $V_{OCM}$  Frequency Response for Various Supplies

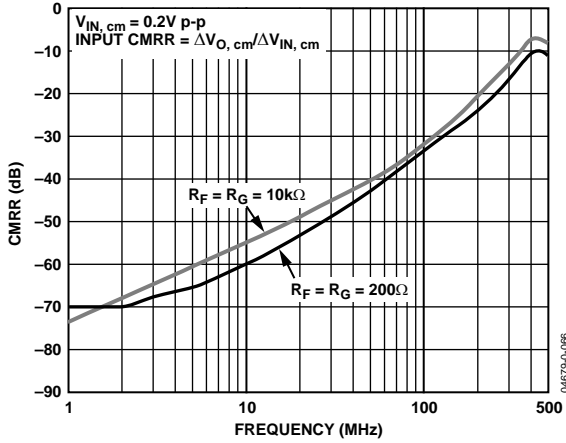


Figure 38. CMRR vs. Frequency

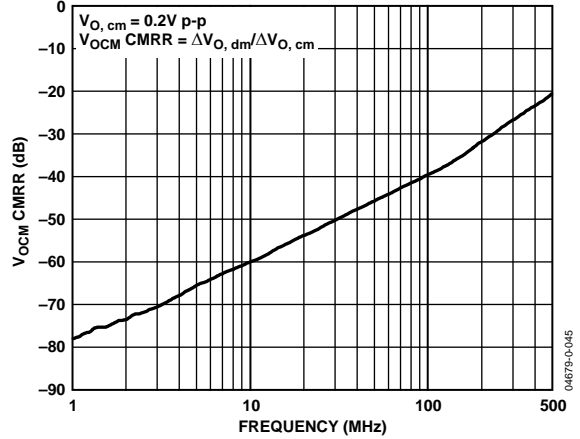


Figure 41.  $V_{OCM}$  CMRR vs. Frequency

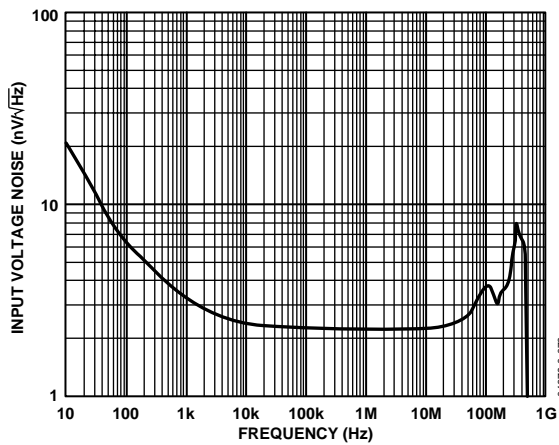


Figure 39. Input Voltage Noise vs. Frequency

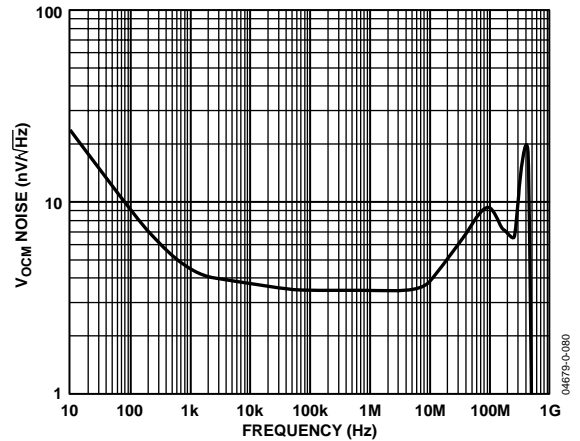


Figure 42.  $V_{OCM}$  Voltage Noise vs. Frequency

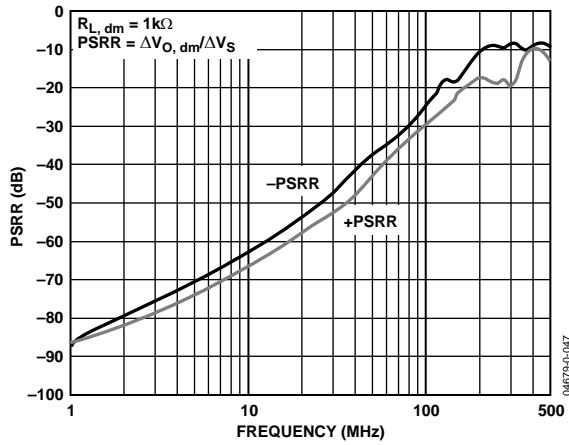


Figure 43. PSRR vs. Frequency

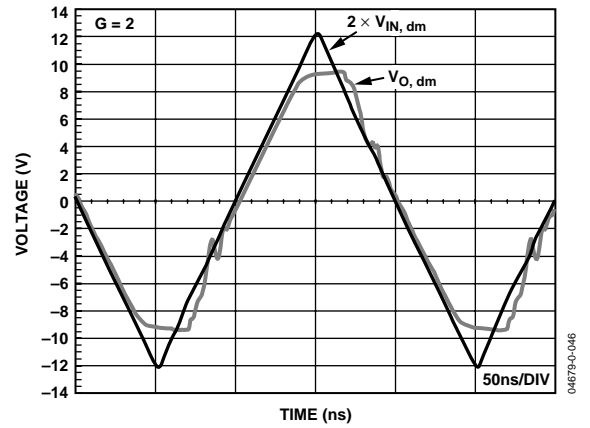


Figure 46. Overdrive Recovery

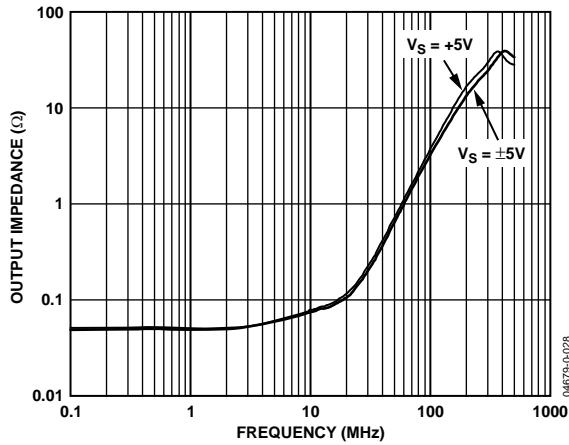


Figure 44. Single-Ended Output Impedance vs. Frequency

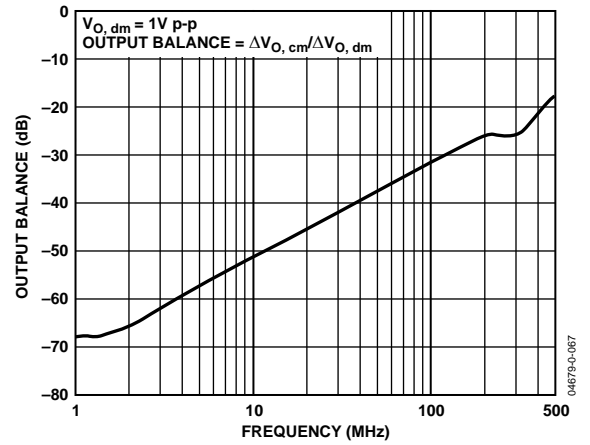


Figure 47. Output Balance vs. Frequency

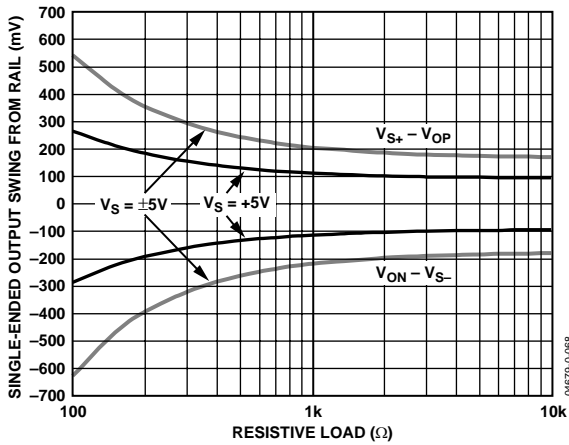


Figure 45. Output Saturation Voltage vs. Output Load

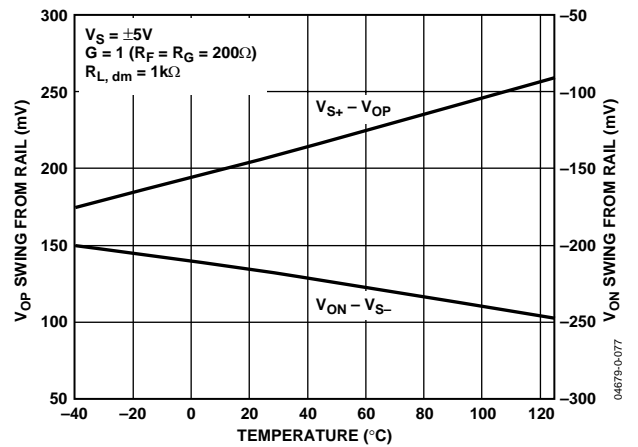


Figure 48. Output Saturation Voltage vs. Temperature

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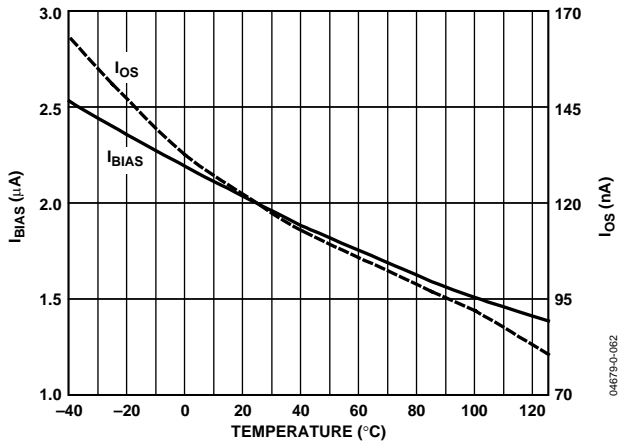


Figure 49. Input Bias and Offset Current vs. Temperature

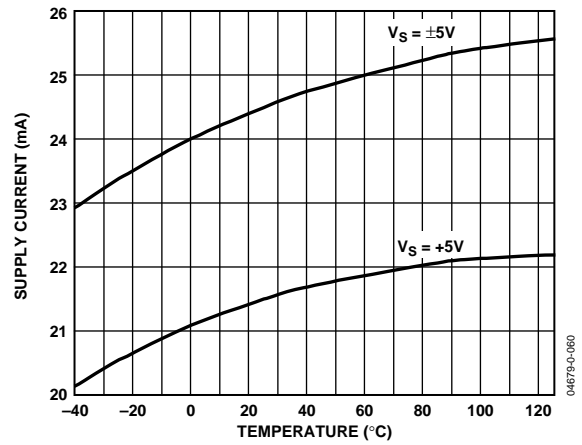


Figure 52. Supply Current vs. Temperature

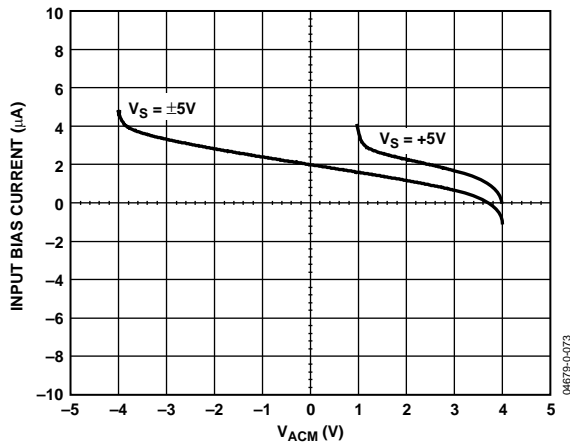


Figure 50. Input Bias Current vs. Input Common-Mode Voltage

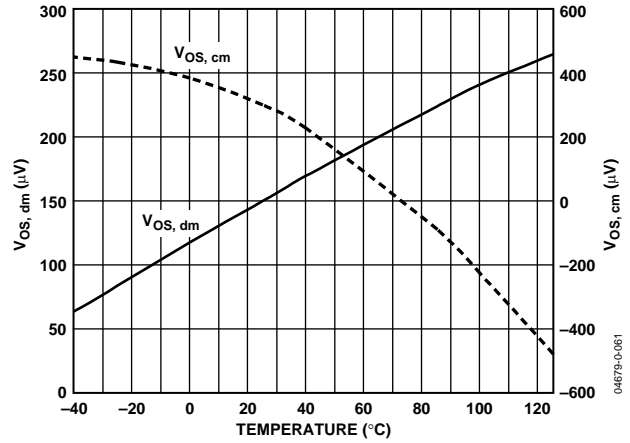


Figure 53. Offset Voltage vs. Temperature

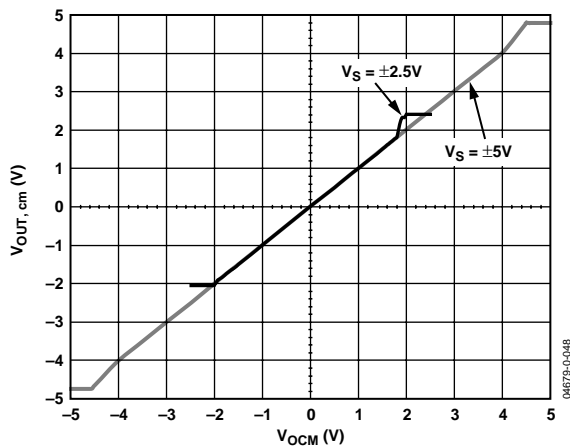


Figure 51.  $V_{O, cm}$  vs.  $V_{OCM}$  Input Voltage

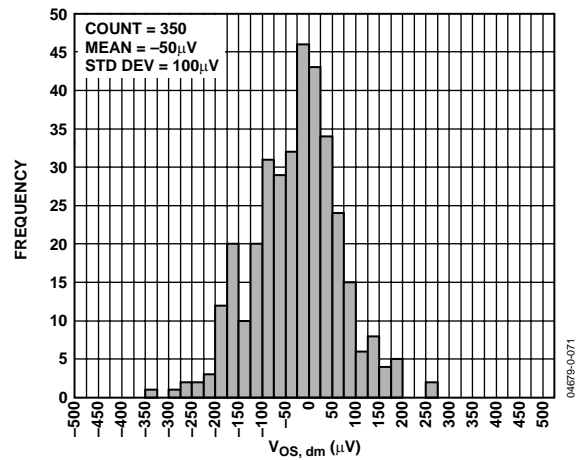


Figure 54.  $V_{OS, dm}$  Distribution



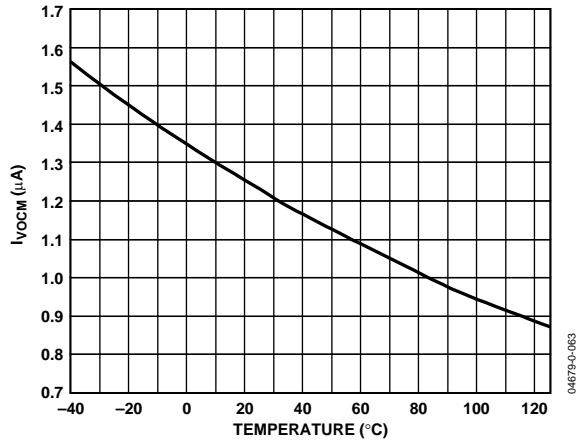


Figure 55.  $V_{OCM}$  Bias Current vs. Temperature

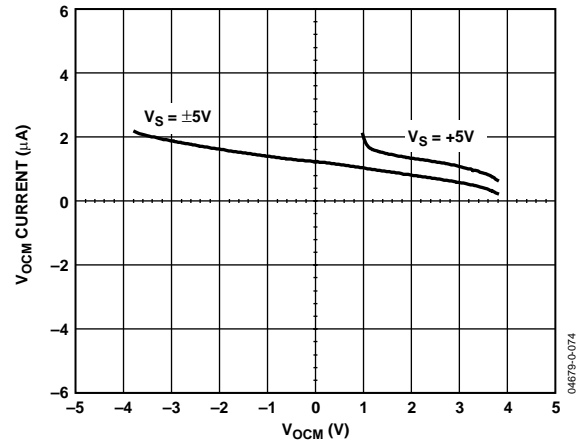


Figure 56.  $V_{OCM}$  Bias Current vs.  $V_{OCM}$  Input Voltage

# AD8139

## THEORY OF OPERATION

The AD8139 is a high speed, low noise differential amplifier fabricated on the Analog Devices second generation eXtra Fast Complementary Bipolar (XFCB) process. It is designed to provide two closely balanced differential outputs in response to either differential or single-ended input signals. Differential gain is set by external resistors, similar to traditional voltage-feedback operational amplifiers. The common-mode level of the output voltage is set by a voltage at the  $V_{OCM}$  pin and is independent of the input common-mode voltage. The AD8139 has an H-bridge input stage for high slew rate, low noise, and low distortion operation and rail-to-rail output stages that provide maximum dynamic output range. This set of features allows for convenient single-ended-to-differential conversion, a common need to take advantage of modern high resolution ADCs with differential inputs.

### TYPICAL CONNECTION AND DEFINITION OF TERMS

Figure 57 shows a typical connection for the AD8139, using matched external  $R_F/R_G$  networks. The differential input terminals of the AD8139,  $V_{AP}$  and  $V_{AN}$ , are used as summing junctions. An external reference voltage applied to the  $V_{OCM}$  terminal sets the output common-mode voltage. The two output terminals,  $V_{OP}$  and  $V_{ON}$ , move in opposite directions in a balanced fashion in response to an input signal.

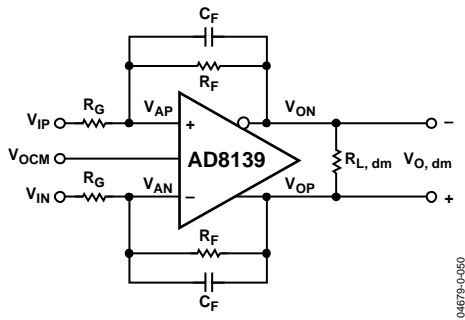


Figure 57. Typical Connection

The differential output voltage is defined as

$$V_{O, dm} = V_{OP} - V_{ON} \quad (1)$$

Common-mode voltage is the average of two voltages. The output common-mode voltage is defined as

$$V_{O, cm} = \frac{V_{OP} + V_{ON}}{2} \quad (2)$$

### Output Balance

Output balance is a measure of how well  $V_{OP}$  and  $V_{ON}$  are matched in amplitude and how precisely they are 180 degrees out of phase with each other. It is the internal common-mode feedback loop that forces the signal component of the output common-mode towards zero, resulting in the near perfectly

balanced differential outputs of identical amplitude and exactly 180 degrees out of phase. The output balance performance does not require tightly matched external components, nor does it require that the feedback factors of each loop be equal to each other. Low frequency output balance is limited ultimately by the mismatch of an on-chip voltage divider, which is trimmed for optimum performance.

Output balance is measured by placing a well matched resistor divider across the differential voltage outputs and comparing the signal at the divider's midpoint with the magnitude of the differential output. By this definition, output balance is equal to the magnitude of the change in output common-mode voltage divided by the magnitude of the change in output differential-mode voltage:

$$\text{Output Balance} = \frac{\Delta V_{O, cm}}{\Delta V_{O, dm}} \quad (3)$$

The block diagram of the AD8139 in Figure 58 shows the external differential feedback loop ( $R_F/R_G$  networks and the differential input transconductance amplifier,  $G_{DIFF}$ ) and the internal common-mode feedback loop (voltage divider across  $V_{OP}$  and  $V_{ON}$  and the common-mode input transconductance amplifier,  $G_{CM}$ ). The differential negative feedback drives the voltages at the summing junctions  $V_{AN}$  and  $V_{AP}$  to be essentially equal to each other.

$$V_{AN} = V_{AP} \quad (4)$$

The common-mode feedback loop drives the output common-mode voltage, sampled at the midpoint of the two 500  $\Omega$  resistors, to equal the voltage set at the  $V_{OCM}$  terminal. This ensures that

$$V_{OP} = V_{OCM} + \frac{V_{O, dm}}{2} \quad (5)$$

and

$$V_{ON} = V_{OCM} - \frac{V_{O, dm}}{2} \quad (6)$$

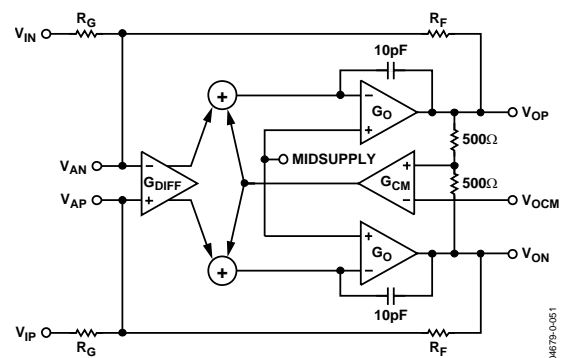


Figure 58. Block Diagram

## APPLICATIONS

### ESTIMATING NOISE, GAIN, AND BANDWIDTH WITH MATCHED FEEDBACK NETWORKS

#### Estimating Output Noise Voltage

The total output noise is calculated as the root-sum-squared total of several statistically independent sources. Since the sources are statistically independent, the contributions of each must be individually included in the root-sum-square calculation. Table 6 lists recommended resistor values and estimates of bandwidth and output differential voltage noise for various closed-loop gains. For most applications, 1% resistors are sufficient.

**Table 6. Recommended Values of Gain-Setting Resistors and Voltage Noise for Various Closed-Loop Gains**

| Gain | $R_G$ ( $\Omega$ ) | $R_F$ ( $\Omega$ ) | 3 dB Bandwidth (MHz) | Total Output Noise (nV/ $\sqrt{\text{Hz}}$ ) |
|------|--------------------|--------------------|----------------------|--|
| 1    | 200                | 200                | 400                  | 5.8  |
| 2    | 200                | 400                | 160                  | 9.3  |
| 5    | 200                | 1 k                | 53                   | 19.7   |
| 10   | 200                | 2 k                | 26                   | 37   |

The differential output voltage noise contains contributions from the AD8139's input voltage noise and input current noise as well as those from the external feedback networks.

The contribution from the input voltage noise spectral density is computed as

$$V_{o\_n1} = v_n \left( 1 + \frac{R_F}{R_G} \right), \text{ or equivalently, } v_n / \beta \quad (7)$$

where  $v_n$  is defined as the input-referred differential voltage noise. This equation is the same as that of traditional op amps.

The contribution from the input current noise of each input is computed as

$$V_{o\_n2} = i_n (R_F) \quad (8)$$

where  $i_n$  is defined as the input noise current of one input. Each input needs to be treated separately since the two input currents are statistically independent processes.

The contribution from each  $R_G$  is computed as

$$V_{o\_n3} = \sqrt{4kTR_G} \left( \frac{R_F}{R_G} \right) \quad (9)$$

This result can be intuitively viewed as the thermal noise of each  $R_G$  multiplied by the magnitude of the differential gain.

The contribution from each  $R_F$  is computed as

$$V_{o\_n4} = \sqrt{4kTR_F} \quad (10)$$

#### Voltage Gain

The behavior of the node voltages of the single-ended-to-differential output topology can be deduced from the previous definitions. Referring to Figure 57, ( $C_F = 0$ ) and setting  $V_{IN} = 0$  one can write

$$\frac{V_{IP} - V_{AP}}{R_G} = \frac{V_{AP} - V_{ON}}{R_F} \quad (11)$$

$$V_{AN} = V_{AP} = V_{OP} \left[ \frac{R_G}{R_F + R_G} \right] \quad (12)$$

Solving the above two equations and setting  $V_{IP}$  to  $V_i$  gives the gain relationship for  $V_{O, dm} / V_i$ .

$$V_{OP} - V_{ON} = V_{O, dm} = \frac{R_F}{R_G} V_i \quad (13)$$

An inverting configuration with the same gain magnitude can be implemented by simply applying the input signal to  $V_{IN}$  and setting  $V_{IP} = 0$ . For a balanced differential input, the gain from  $V_{IN, dm}$  to  $V_{O, dm}$  is also equal to  $R_F / R_G$ , where  $V_{IN, dm} = V_{IP} - V_{IN}$ .

#### Feedback Factor Notation

When working with differential amplifiers, it is convenient to introduce the feedback factor  $\beta$ , which is defined as

$$\beta = \frac{R_G}{R_F + R_G} \quad (14)$$

This notation is consistent with conventional feedback analysis and is very useful, particularly when the two feedback loops are not matched.

#### Input Common-Mode Voltage

The linear range of the  $V_{AN}$  and  $V_{AP}$  terminals extends to within approximately 1 V of either supply rail. Since  $V_{AN}$  and  $V_{AP}$  are essentially equal to each other, they are both equal to the amplifier's input common-mode voltage. Their range is indicated in the Specifications tables as input common-mode range. The voltage at  $V_{AN}$  and  $V_{AP}$  for the connection diagram in Figure 57 can be expressed as

$$V_{AN} = V_{AP} = V_{ACM} = \left( \frac{R_F}{R_F + R_G} \times \frac{(V_{IP} + V_{IN})}{2} \right) + \left( \frac{R_G}{R_F + R_G} \times V_{OCM} \right) \quad (15)$$

where  $V_{ACM}$  is the common-mode voltage present at the amplifier input terminals.

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Using the  $\beta$  notation, Equation 15 can be written as

$$V_{ACM} = \beta V_{OCM} + (1 - \beta)V_{ICM} \quad (16)$$

or equivalently,

$$V_{ACM} = V_{ICM} + \beta(V_{OCM} - V_{ICM}) \quad (17)$$

where  $V_{ICM}$  is the common-mode voltage of the input signal, i.e.,

$$V_{ICM} = \frac{V_{IP} + V_{IN}}{2}$$

For proper operation, the voltages at  $V_{AN}$  and  $V_{AP}$  must stay within their respective linear ranges.

### Calculating Input Impedance

The input impedance of the circuit in Figure 57 will depend on whether the amplifier is being driven by a single-ended or a differential signal source. For balanced differential input signals, the differential input impedance ( $R_{IN, dm}$ ) is simply

$$R_{IN, dm} = 2R_G \quad (18)$$

For a single-ended signal (for example, when  $V_{IN}$  is grounded and the input signal drives  $V_{IP}$ ), the input impedance becomes

$$R_{IN} = \frac{R_G}{1 - \frac{R_F}{2(R_G + R_F)}} \quad (19)$$

The input impedance of a conventional inverting op amp configuration is simply  $R_G$ , but it is higher in Equation 19 because a fraction of the differential output voltage appears at the summing junctions,  $V_{AN}$  and  $V_{AP}$ . This voltage partially bootstraps the voltage across the input resistor  $R_G$ , leading to the increased input resistance.

### Input Common-Mode Swing Considerations

In some single-ended-to-differential applications, when using a single-supply voltage attention must be paid to the swing of the input common-mode voltage,  $V_{ACM}$ .

Consider the case in Figure 59, where  $V_{IN}$  is 5 V p-p swinging about a baseline at ground and  $V_{REF}$  is connected to ground.

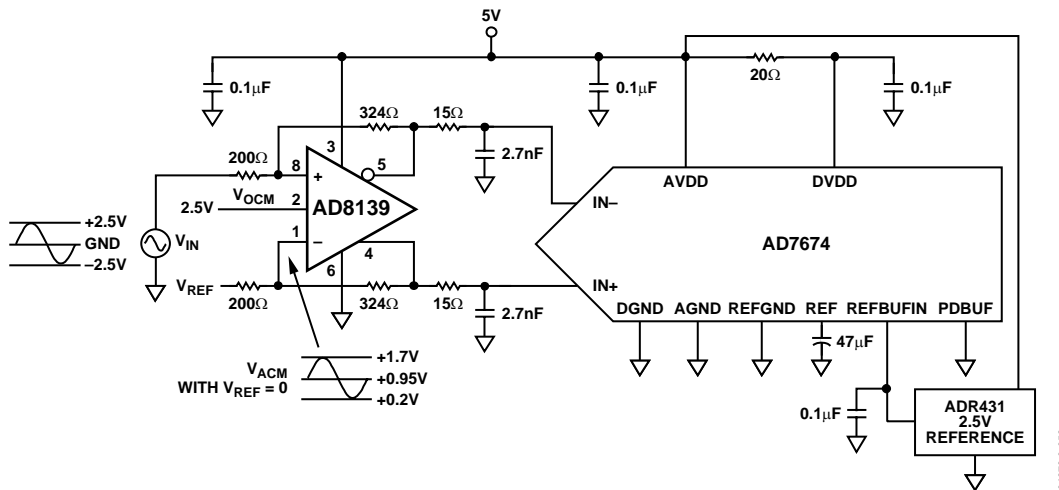


Figure 59. AD8139 Driving AD7674, 18-Bit, 800 kSPS A/D Converter

The circuit has a differential gain of 1.6 and  $\beta = 0.38$ .  $V_{ICM}$  has an amplitude of 2.5 V p-p and is swinging about ground. Using the results in Equation 16, the common-mode voltage at the AD8139's inputs,  $V_{ACM}$ , is a 1.5 V p-p signal swinging about a baseline of 0.95 V. The maximum negative excursion of  $V_{ACM}$  in this case is 0.2 V, which exceeds the lower input common-mode voltage limit.

One way to avoid the input common-mode swing limitation is to bias  $V_{IN}$  and  $V_{REF}$  at midsupply. In this case,  $V_{IN}$  is 5 V p-p swinging about a baseline at 2.5 V and  $V_{REF}$  is connected to a low-Z 2.5 V source.  $V_{ICM}$  now has an amplitude of 2.5 V p-p and is swinging about 2.5 V. Using the results in Equation 17,  $V_{ACM}$  is calculated to be equal to  $V_{ICM}$  because  $V_{OCM} = V_{ICM}$ . Therefore,  $V_{ACM}$  swings from 1.25 V to 3.75 V, which is well within the input common-mode voltage limits of the AD8139. Another benefit seen in this example is that since  $V_{OCM} = V_{ACM} = V_{ICM}$  no wasted common-mode current flows. Figure 60 illustrates how to provide the low-Z bias voltage. For situations that do not require a precise reference, a simple voltage divider will suffice to develop the input voltage to the buffer.

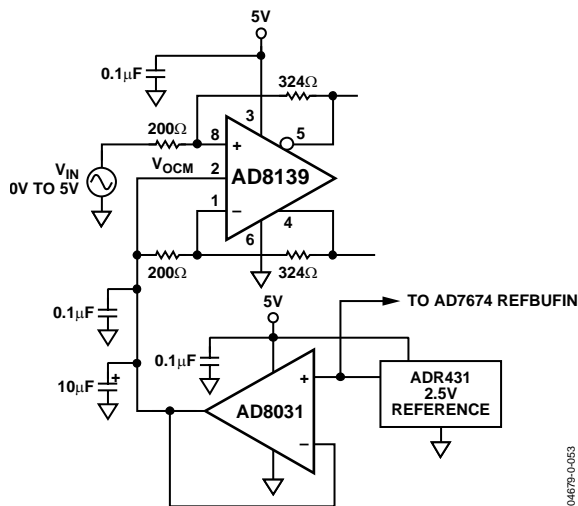


Figure 60. Low-Z 2.5 V Buffer

Another way to avoid the input common-mode swing limitation is to use dual power supplies on the AD8139. In this case, the biasing circuitry is not required.

**Bandwidth Versus Closed-Loop Gain**

The AD8139's 3 dB bandwidth decreases proportionally to increasing closed-loop gain in the same way as a traditional voltage feedback operational amplifier. For closed-loop gains greater than 4, the bandwidth obtained for a specific gain can be estimated as

$$f - 3 \text{ dB}, V_{OUT, dm} = \frac{R_G}{R_G + R_F} \times (300 \text{ MHz}) \tag{20}$$

or equivalently,  $\beta(300 \text{ MHz})$ .

This estimate assumes a minimum 90 degree phase margin for the amplifier loop, which is a condition approached for gains greater than 4. Lower gains will show more bandwidth than predicted by the equation due to the peaking produced by the lower phase margin.

**Estimating DC Errors**

Primary differential output offset errors in the AD8139 are due to three major components: the input offset voltage, the offset between the  $V_{AN}$  and  $V_{AP}$  input currents interacting with the feedback network resistances, and the offset produced by the dc voltage difference between the input and output common-mode voltages in conjunction with matching errors in the feedback network.

The first output error component is calculated as

$$V_{o\_e1} = V_{IO} \left( \frac{R_F + R_G}{R_G} \right), \text{ or equivalently as } V_{IO}/\beta \tag{21}$$

where  $V_{IO}$  is the input offset voltage. The input offset voltage of the AD8139 is laser trimmed and guaranteed to be less than 500  $\mu\text{V}$ .

The second error is calculated as

$$V_{o\_e2} = I_{IO} \left( \frac{R_F + R_G}{R_G} \right) \left( \frac{R_G R_F}{R_F + R_G} \right) = I_{IO} (R_F) \tag{22}$$

where  $I_{IO}$  is defined as the offset between the two input bias currents.

The third error voltage is calculated as

$$V_{o\_e3} = \Delta nr \times (V_{ICM} - V_{OCM}) \tag{23}$$

where  $\Delta nr$  is the fractional mismatch between the two feedback resistors.

The total differential offset error is the sum of these three error sources.

**Other Impact of Mismatches in the Feedback Networks**

The internal common-mode feedback network will still force the output voltages to remain balanced, even when the  $R_F/R_G$  feedback networks are mismatched. The mismatch will, however, cause a gain error proportional to the feedback network mismatch.

Ratio-matching errors in the external resistors will degrade the ability to reject common-mode signals at the  $V_{AN}$  and  $V_{IN}$  input terminals, much the same as with a four-resistor difference amplifier made from a conventional op amp. Ratio-matching errors will also produce a differential output component that is equal to the  $V_{OCM}$  input voltage times the difference between the feedback factors ( $\beta$ s). In most applications using 1% resistors, this component amounts to a differential dc offset at the output that is small enough to be ignored.

# AD8139

## Driving a Capacitive Load

A purely capacitive load will react with the bondwire and pin inductance of the AD8139, resulting in high frequency ringing in the transient response and loss of phase margin. One way to minimize this effect is to place a small resistor in series with each output to buffer the load capacitance, see Figure 6 and Figure 61. The resistor and load capacitance will form a first-order low-pass filter; therefore, the resistor value should be as small as possible. In some cases, the ADCs require small series resistors to be added on their inputs.

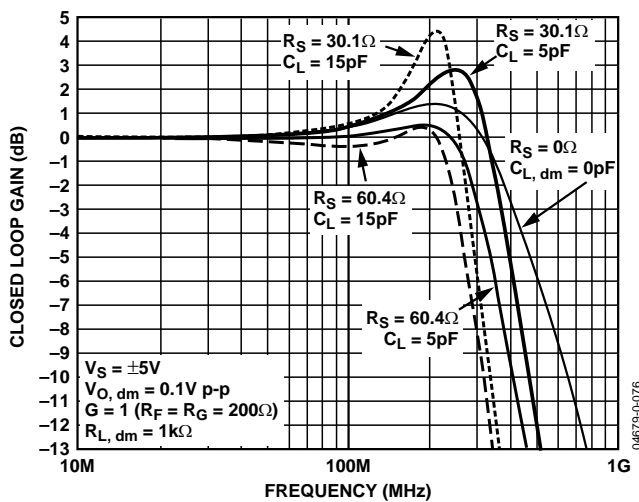


Figure 61. Frequency Response for Various Capacitive Load and Series Resistance

The Typical Performance Characteristics that illustrate transient response versus the capacitive load were generated using series resistors in each output and a differential capacitive load.

## Layout Considerations

Standard high speed PCB layout practices should be adhered to when designing with the AD8139. A solid ground plane is recommended and good wideband power supply decoupling networks should be placed as close as possible to the supply pins.

To minimize stray capacitance at the summing nodes, the copper in all layers under all traces and pads that connect to the summing nodes should be removed. Small amounts of stray summing-node capacitance will cause peaking in the frequency response, and large amounts can cause instability. If some stray summing-node capacitance is unavoidable, its effects can be compensated for by placing small capacitors across the feedback resistors.

## Terminating a Single-Ended Input

Controlled impedance interconnections are used in most high speed signal applications, and they require at least one line termination. In analog applications, a matched resistive termination is generally placed at the load end of the line. This section deals with how to properly terminate a single-ended input to the AD8139.

The input resistance presented by the AD8139 input circuitry is seen in parallel with the termination resistor, and its loading effect must be taken into account. The Thevenin equivalent circuit of the driver, its source resistance, and the termination resistance must all be included in the calculation as well. An exact solution to the problem requires the solution of several simultaneous algebraic equations and is beyond the scope of this data sheet. An iterative solution is also possible and simpler, especially considering the fact that standard 1% resistor values are generally used.

Figure 62 shows the AD8139 in a unity-gain configuration driving the AD6645, which is a 14-bit high speed ADC, and with the following discussion, provides a good example of how to provide a proper termination in a 50  $\Omega$  environment.

The termination resistor,  $R_T$ , in parallel with the 268  $\Omega$  input resistance of the AD8139 circuit (calculated using Equation 19), yields an overall input resistance of 50  $\Omega$  that is seen by the signal source. In order to have matched feedback loops, each loop must have the same  $R_G$  if they have the same  $R_F$ . In the input (upper) loop,  $R_G$  is equal to the 200  $\Omega$  resistor in series with the (+) input plus the parallel combination of  $R_T$  and the source resistance of 50  $\Omega$ . In the upper loop,  $R_G$  is therefore equal to 228  $\Omega$ . The closest standard 1% value to 228  $\Omega$  is 226  $\Omega$  and is used for  $R_G$  in the lower loop. Greater accuracy could be achieved by using two resistors in series to obtain a resistance closer to 228  $\Omega$ .

Things get more complicated when it comes to determining the feedback resistor values. The amplitude of the signal source generator  $V_s$  is two times the amplitude of its output signal when terminated in 50  $\Omega$ . Thus, a 2 V p-p terminated amplitude is produced by a 4 V p-p amplitude from  $V_s$ . The Thevenin equivalent circuit of the signal source and  $R_T$  must be used when calculating the closed-loop gain because in the upper loop  $R_G$  is split between the 200  $\Omega$  resistor and the Thevenin resistance looking back toward the source. The Thevenin voltage of the signal source is greater than the signal source output voltage when terminated in 50  $\Omega$  because  $R_T$  must always be greater than 50  $\Omega$ . In this case, it is 61.9  $\Omega$  and the Thevenin voltage and resistance are 2.2 V p-p and 28  $\Omega$ , respectively. Now the upper input branch can be viewed as a 2.2 V p-p source in series with 228  $\Omega$ . Since this is a unity-gain application, a 2 V p-p differential output is required, and  $R_F$  must therefore be  $228 \times (2/2.2) = 206 \Omega$ . The closest standard value to this is 205  $\Omega$ .

When generating the Typical Performance Characteristics data, the measurements were calibrated to take the effects of the terminations on closed-loop gain into account.

Since this is a single-ended-to-differential application on a single supply, the input common-mode voltage swing must be checked. From Figure 62,  $\beta = 0.52$ ,  $V_{OCM} = 2.4\text{ V}$ , and  $V_{ICM}$  is 1.1 V p-p swinging about ground. Using Equation 16,  $V_{ACM}$  is calculated to be 0.53 V p-p swinging about a baseline of 1.25 V, and the minimum negative excursion is approximately 1 V.

### Exposed Paddle (EP)

The SOIC-8 and LFCSP packages have an exposed paddle on the underside of its body. In order to achieve the specified thermal resistance, it must have a good thermal connection to one of the PCB planes. The exposed paddle must be soldered to a pad on top of the board that is connected to an inner plane with several thermal vias.

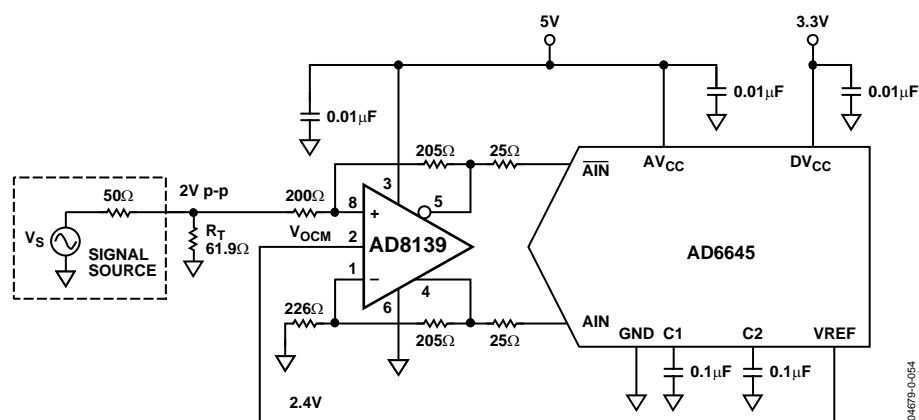


Figure 62. AD8139 Driving AD6645, 14-Bit, 80 MSPS/105 MSPS A/D Converter

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# AD8139

## OUTLINE DIMENSIONS

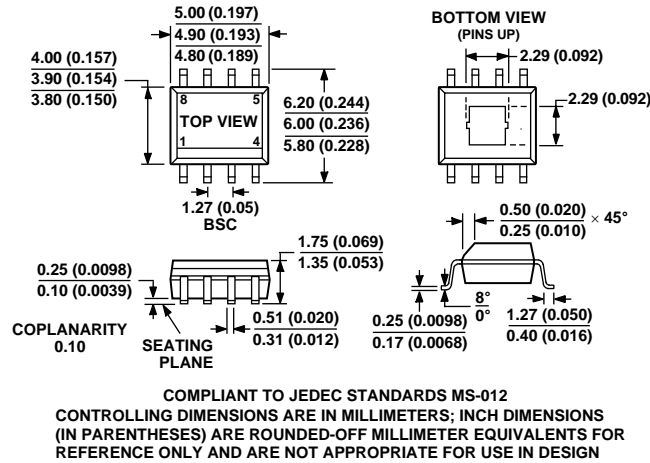


Figure 63. 8-Lead Standard Small Outline Package with Exposed Pad [SOIC/EP], Narrow Body (RD-8-1)—Dimensions shown in millimeters and (inches)

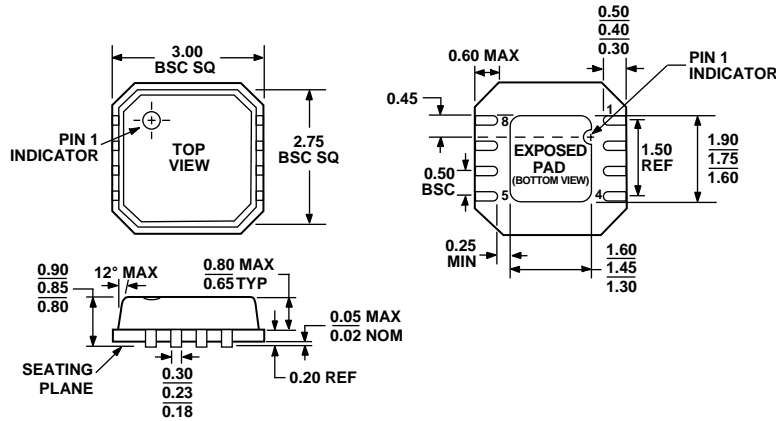


Figure 64. 8-Lead Lead Frame Chip Scale Package [LFCSP], 3 mm x 3 mm Body (CP-8-2)—Dimensions shown in millimeters

## ORDERING GUIDE

| Model                         | Temperature Range | Package Description                          | Package Option | Branding |
|-------------------------------|-------------------|--|----------------|----------|
| AD8139ARD                     | -40°C to +125°C   | 8-Lead Small Outline Package (SOIC)          | RD-8-1         |          |
| AD8139ARD-REEL                | -40°C to +125°C   | 8-Lead Small Outline Package (SOIC)          | RD-8-1         |          |
| AD8139ARD-REEL7               | -40°C to +125°C   | 8-Lead Small Outline Package (SOIC)          | RD-8-1         |          |
| AD8139ARDZ <sup>1</sup>       | -40°C to +125°C   | 8-Lead Small Outline Package (SOIC)          | RD-8-1         |          |
| AD8139ARDZ-REEL <sup>1</sup>  | -40°C to +125°C   | 8-Lead Small Outline Package (SOIC)          | RD-8-1         |          |
| AD8139ARDZ-REEL7 <sup>1</sup> | -40°C to +125°C   | 8-Lead Small Outline Package (SOIC)          | RD-8-1         |          |
| AD8139ACP-R2                  | -40°C to +125°C   | 8-Lead Lead Frame Chip Scale Package (LFCSP) | CP-8-2         | HEB      |
| AD8139ACP-REEL                | -40°C to +125°C   | 8-Lead Lead Frame Chip Scale Package (LFCSP) | CP-8-2         | HEB      |
| AD8139ACP-REEL7               | -40°C to +125°C   | 8-Lead Lead Frame Chip Scale Package (LFCSP) | CP-8-2         | HEB      |
| AD8139ACPZ-R2 <sup>1</sup>    | -40°C to +125°C   | 8-Lead Lead Frame Chip Scale Package (LFCSP) | CP-8-2         | HEB      |
| AD8139ACPZ-REEL <sup>1</sup>  | -40°C to +125°C   | 8-Lead Lead Frame Chip Scale Package (LFCSP) | CP-8-2         | HEB      |
| AD8139ACPZ-REEL7 <sup>1</sup> | -40°C to +125°C   | 8-Lead Lead Frame Chip Scale Package (LFCSP) | CP-8-2         | HEB      |

<sup>1</sup> Z = Pb-free part.