

# LMP2231 Single Micropower, 1.6V, Precision Operational Amplifier with CMOS Inputs

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## FEATURES

(For  $V_S = 5V$ ,  $T_A = 25^\circ C$ , Typical Unless Otherwise Noted)

- Supply Current 10  $\mu A$
- Operating Voltage Range 1.6V to 5.5V
- $TCV_{OS}$  (LMP2231A)  $\pm 0.4 \mu V/^\circ C$  (max)
- $TCV_{OS}$  (LMP2231B)  $\pm 2.5 \mu V/^\circ C$  (max)
- $V_{OS} \pm 150 \mu V$  (max)
- Input Bias Current 20 fA
- PSRR 120 dB
- CMRR 97 dB
- Open Loop Gain 120 dB
- Gain Bandwidth Product 130 kHz
- Slew Rate 58 V/ms
- Input Voltage Noise,  $f = 1 \text{ kHz}$  60 nV/ $\sqrt{Hz}$
- Temperature Range  $-40^\circ C$  to  $125^\circ C$

## APPLICATIONS

- Precision Instrumentation Amplifiers
- Battery Powered Medical Instrumentation
- High Impedance Sensors
- Strain Gauge Bridge Amplifier
- Thermocouple Amplifiers

## DESCRIPTION

The LMP2231 is a single micropower precision amplifier designed for battery powered applications. The 1.6V to 5.5V operating supply voltage range and quiescent power consumption of only 16  $\mu W$  extend the battery life in portable battery operated systems. The LMP2231 is part of the LMP™ precision amplifier family. The high impedance CMOS input makes it ideal for instrumentation and other sensor interface applications.

The LMP2231 has a maximum offset of 150  $\mu V$  and maximum offset voltage drift of only  $0.4 \mu V/^\circ C$  along with low bias current of only  $\pm 20$  fA. These precise specifications make the LMP2231 a great choice for maintaining system accuracy and long term stability.

The LMP2231 has a rail-to-rail output that swings 15 mV from the supply voltage, which increases system dynamic range. The common mode input voltage range extends 200 mV below the negative supply, thus the LMP2231 is ideal for use in single supply applications with ground sensing.

The LMP2231 is offered in 5-Pin SOT-23 and 8-pin SOIC packages.

The dual and quad versions of this product are also available. The dual, LMP2232 is offered in 8-pin SOIC and VSSOP. The quad, LMP2234 is offered in 14-pin SOIC and TSSOP.



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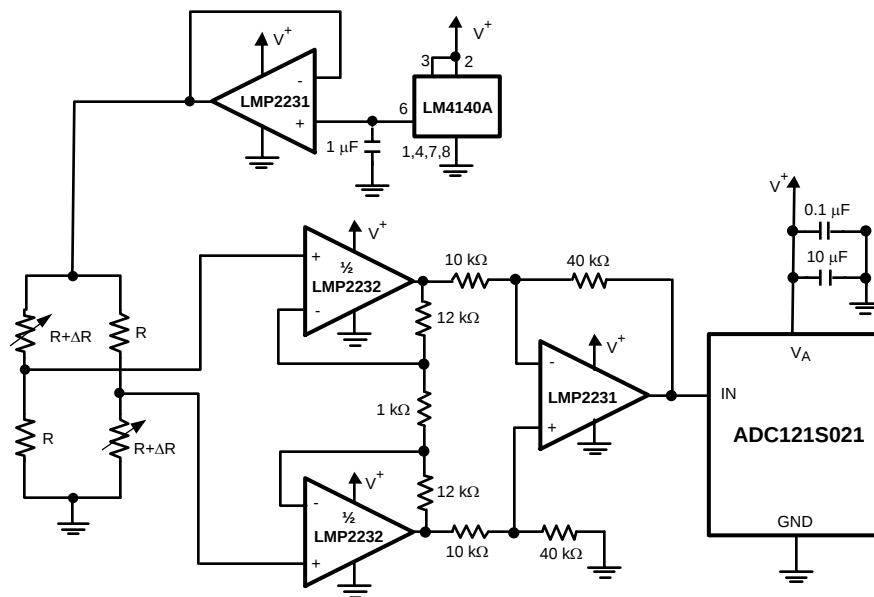
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## Typical Application



### Figure 1. Strain Gauge Bridge Amplifier



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### Absolute Maximum Ratings<sup>(1)(2)</sup>

|                                                                                                                                                                                |                  |                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|--------------------------|
| ESD Tolerance <sup>(3)</sup>                                                                                                                                                   | Human Body Model | 2000V                    |
|                                                                                                                                                                                | Machine Model    | 100V                     |
| Differential Input Voltage                                                                                                                                                     |                  | ±300 mV                  |
| Supply Voltage ( $V_S = V^+ - V^-$ )                                                                                                                                           |                  | 6V                       |
| Voltage on Input/Output Pins                                                                                                                                                   |                  | $V^+ + 0.3V, V^- - 0.3V$ |
| Storage Temperature Range                                                                                                                                                      |                  | -65°C to 150°C           |
| Junction Temperature <sup>(4)</sup>                                                                                                                                            |                  | 150°C                    |
| For soldering specifications: see product folder at <a href="http://www.ti.com">www.ti.com</a> and <a href="http://www.ti.com/lit/SNOA549">http://www.ti.com/lit/SNOA549</a> . |                  |                          |

- (1) Absolute Maximum Ratings indicate limits beyond which damage may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not ensured. For ensured specifications and test conditions, see the Electrical Characteristics.
- (2) If Military/Aerospace specified devices are required, please contact the TI Sales Office/ Distributors for availability and specifications.
- (3) Human Body Model, applicable std. MIL-STD-883, Method 3015.7. Machine Model, applicable std. JESD22-A115-A (ESD MM std. of JEDEC)/Field-Induced Charge-Device Model, applicable std. JESD22-C101-C (ESD FICDM std. of JEDEC).
- (4) The maximum power dissipation is a function of  $T_{J(MAX)}$ ,  $\theta_{JA}$ . The maximum allowable power dissipation at any ambient temperature is  $P_D = (T_{J(MAX)} - T_A) / \theta_{JA}$ . All numbers apply for packages soldered directly onto a PC Board.

## Operating Ratings<sup>(1)</sup>

|                                                             |              |                |
|-------------------------------------------------------------|--------------|----------------|
| Operating Temperature Range <sup>(2)</sup>                  |              | –40°C to 125°C |
| Supply Voltage ( $V_S = V^+ - V^-$ )                        |              | 1.6V to 5.5V   |
| Package Thermal Resistance ( $\theta_{JA}$ ) <sup>(2)</sup> | 5-Pin SOT-23 | 160.6 °C/W     |
|                                                             | 8-Pin SOIC   | 116.2 °C/W     |

- (1) Absolute Maximum Ratings indicate limits beyond which damage may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not ensured. For ensured specifications and test conditions, see the Electrical Characteristics.
- (2) The maximum power dissipation is a function of  $T_{J(MAX)}$ ,  $\theta_{JA}$ . The maximum allowable power dissipation at any ambient temperature is  $P_D = (T_{J(MAX)} - T_A) / \theta_{JA}$ . All numbers apply for packages soldered directly onto a PC Board.

## 5V DC Electrical Characteristics<sup>(1)</sup>

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                     | Conditions                                                                          | Min <sup>(2)</sup>  | Typ <sup>(3)</sup> | Max <sup>(2)</sup>                       | Units                        |
|------------|-------------------------------|-------------------------------------------------------------------------------------|---------------------|--------------------|------------------------------------------|------------------------------|
| $V_{OS}$   | Input Offset Voltage          |                                                                                     |                     | $\pm 10$           | $\pm 150$<br><b><math>\pm 230</math></b> | $\mu\text{V}$                |
| $TCV_{OS}$ | Input Offset Voltage Drift    | LMP2231A                                                                            |                     | $\pm 0.3$          | $\pm 0.4$                                | $\mu\text{V}/^\circ\text{C}$ |
|            |                               | LMP2231B                                                                            |                     | $\pm 0.3$          | $\pm 2.5$                                |                              |
| $I_{BIAS}$ | Input Bias Current            |                                                                                     |                     | 0.02               | $\pm 1$<br><b><math>\pm 50</math></b>    | pA                           |
| $I_{OS}$   | Input Offset Current          |                                                                                     |                     | 5                  |                                          | fA                           |
| CMRR       | Common Mode Rejection Ratio   | $0\text{V} \leq V_{CM} \leq 4\text{V}$                                              | 81<br><b>80</b>     | 97                 |                                          | dB                           |
| PSRR       | Power Supply Rejection Ratio  | $1.6\text{V} \leq V^+ \leq 5.5\text{V}$<br>$V^- = 0\text{V}$ , $V_{CM} = 0\text{V}$ | 83<br><b>83</b>     | 120                |                                          | dB                           |
| CMVR       | Common Mode Voltage Range     | CMRR $\geq 80\text{ dB}$<br>CMRR $\geq 79\text{ dB}$                                | –0.2<br><b>–0.2</b> |                    | 4.2<br><b>4.2</b>                        | V                            |
| $A_{VOL}$  | Large Signal Voltage Gain     | $V_O = 0.3\text{V}$ to $4.7\text{V}$<br>$R_L = 10\text{ k}\Omega$ to $V^+/2$        | 110<br><b>108</b>   | 120                |                                          | dB                           |
| $V_O$      | Output Swing High             | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$       |                     | 17                 | 50<br><b>50</b>                          | mV<br>from either<br>rail    |
|            | Output Swing Low              | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$      |                     | 17                 | 50<br><b>50</b>                          |                              |
| $I_O$      | Output Current <sup>(4)</sup> | Sourcing, $V_O$ to $V^-$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$                   | 27<br><b>19</b>     | 30                 |                                          | mA                           |
|            |                               | Sinking, $V_O$ to $V^+$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$                   | 17<br><b>12</b>     | 22                 |                                          |                              |
| $I_S$      | Supply Current                |                                                                                     |                     | 10                 | 16<br><b>18</b>                          | $\mu\text{A}$                |

- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.
- (4) The short circuit test is a momentary open loop test.

## 5V AC Electrical Characteristics<sup>(1)</sup>

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                            | Conditions                                       | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup> | Units                        |
|------------|--------------------------------------|--------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| GBW        | Gain-Bandwidth Product               | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$ |                    | 130                |                    | kHz                          |
| SR         | Slew Rate                            | $A_V = +1$                                       | Falling Edge       | 33<br><b>32</b>    | 58                 | V/ms                         |
|            |                                      |                                                  | Rising Edge        | 33<br><b>32</b>    | 48                 |                              |
| $\theta_m$ | Phase Margin                         | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$ |                    | 78                 |                    | deg                          |
| $G_m$      | Gain Margin                          | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$ |                    | 27                 |                    | dB                           |
| $e_n$      | Input-Referred Voltage Noise Density | $f = 1\text{ kHz}$                               |                    | 60                 |                    | $\text{nV}/\sqrt{\text{Hz}}$ |
|            | Input-Referred Voltage Noise         | 0.1 Hz to 10 Hz                                  |                    | 2.3                |                    | $\mu\text{V}_{PP}$           |
| $i_n$      | Input-Referred Current Noise         | $f = 1\text{ kHz}$                               |                    | 10                 |                    | $\text{fA}/\sqrt{\text{Hz}}$ |
| THD+N      | Total Harmonic Distortion + Noise    | $f = 100\text{ Hz}$ , $R_L = 10\text{ k}\Omega$  |                    | 0.002              |                    | %                            |

- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.

## 3.3V DC Electrical Characteristics<sup>(1)</sup>

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 3.3\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                    | Conditions                                                                          | Min <sup>(2)</sup>  | Typ <sup>(3)</sup> | Max <sup>(2)</sup>                       | Units                        |
|------------|------------------------------|-------------------------------------------------------------------------------------|---------------------|--------------------|------------------------------------------|------------------------------|
| $V_{OS}$   | Input Offset Voltage         |                                                                                     |                     | $\pm 10$           | $\pm 160$<br><b><math>\pm 250</math></b> | $\mu\text{V}$                |
| $TCV_{OS}$ | Input Offset Voltage Drift   | LMP2231A                                                                            |                     | $\pm 0.3$          | $\pm 0.4$                                | $\mu\text{V}/^\circ\text{C}$ |
|            |                              | LMP2231B                                                                            |                     | $\pm 0.3$          | $\pm 2.5$                                |                              |
| $I_{BIAS}$ | Input Bias Current           |                                                                                     |                     | 0.02               | $\pm 1$<br><b><math>\pm 50</math></b>    | pA                           |
| $I_{OS}$   | Input Offset Current         |                                                                                     |                     | 5                  |                                          | fA                           |
| CMRR       | Common Mode Rejection Ratio  | $0\text{V} \leq V_{CM} \leq 2.3\text{V}$                                            | 79<br><b>77</b>     | 92                 |                                          | dB                           |
| PSRR       | Power Supply Rejection Ratio | $1.6\text{V} \leq V^+ \leq 5.5\text{V}$<br>$V^- = 0\text{V}$ , $V_{CM} = 0\text{V}$ | 83<br><b>83</b>     | 120                |                                          | dB                           |
| CMVR       | Common Mode Voltage Range    | CMRR $\geq 78\text{ dB}$<br>CMRR $\geq 77\text{ dB}$                                | -0.2<br><b>-0.2</b> |                    | 2.5<br><b>2.5</b>                        | V                            |
| $A_{VOL}$  | Large Signal Voltage Gain    | $V_O = 0.3\text{V}$ to $3\text{V}$<br>$R_L = 10\text{ k}\Omega$ to $V^+/2$          | 108<br><b>107</b>   | 120                |                                          | dB                           |
| $V_O$      | Output Swing High            | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$       |                     | 14                 | 50<br><b>50</b>                          | mV<br>from either<br>rail    |
|            | Output Swing Low             | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$      |                     | 14                 | 50<br><b>50</b>                          |                              |

- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.

### 3.3V DC Electrical Characteristics<sup>(1)</sup> (continued)

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 3.3\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol | Parameter                     | Conditions                                                        | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup> | Units         |
|--------|-------------------------------|-------------------------------------------------------------------|--------------------|--------------------|--------------------|---------------|
| $I_O$  | Output Current <sup>(4)</sup> | Sourcing, $V_O$ to $V^-$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$ | 11<br><b>8</b>     | 14                 |                    | mA            |
|        |                               | Sinking, $V_O$ to $V^+$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$ | 8<br><b>5</b>      | 11                 |                    |               |
| $I_S$  | Supply Current                |                                                                   |                    | 10                 | 15<br><b>16</b>    | $\mu\text{A}$ |

(4) The short circuit test is a momentary open loop test.

### 3.3V AC Electrical Characteristics<sup>(1)</sup>

Unless otherwise is specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 3.3\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                            | Conditions                                                     | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup> | Units                        |
|------------|--------------------------------------|----------------------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| GBW        | Gain-Bandwidth Product               | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 128                |                    | kHz                          |
| SR         | Slew Rate                            | $A_V = +1$ , $C_L = 20\text{ pF}$<br>$R_L = 10\text{ k}\Omega$ | Falling Edge       | 58                 |                    | V/ms                         |
|            |                                      |                                                                | Rising Edge        | 48                 |                    |                              |
| $\theta_m$ | Phase Margin                         | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 76                 |                    | deg                          |
| $G_m$      | Gain Margin                          | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 26                 |                    | dB                           |
| $e_n$      | Input-Referred Voltage Noise Density | $f = 1\text{ kHz}$                                             |                    | 60                 |                    | $\text{nV}/\sqrt{\text{Hz}}$ |
|            | Input-Referred Voltage Noise         | 0.1 Hz to 10 Hz                                                |                    | 2.4                |                    | $\mu\text{V}_{PP}$           |
| $i_n$      | Input-Referred Current Noise         | $f = 1\text{ kHz}$                                             |                    | 10                 |                    | $\text{fA}/\sqrt{\text{Hz}}$ |
| THD+N      | Total Harmonic Distortion + Noise    | $f = 100\text{ Hz}$ , $R_L = 10\text{ k}\Omega$                |                    | 0.003              |                    | %                            |

- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.

### 2.5V DC Electrical Characteristics<sup>(1)</sup>

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 2.5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                   | Conditions                               | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup>                       | Units                        |
|------------|-----------------------------|------------------------------------------|--------------------|--------------------|------------------------------------------|------------------------------|
| $V_{OS}$   | Input Offset Voltage        |                                          |                    | $\pm 10$           | $\pm 190$<br><b><math>\pm 275</math></b> | $\mu\text{V}$                |
| $TCV_{OS}$ | Input Offset Voltage Drift  | LMP2231A                                 |                    | $\pm 0.3$          | $\pm 0.4$                                | $\mu\text{V}/^\circ\text{C}$ |
|            |                             | LMP2231B                                 |                    | $\pm 0.3$          | $\pm 2.5$                                |                              |
| $I_{BIAS}$ | Input Bias Current          |                                          |                    | 0.02               | $\pm 1.0$<br><b><math>\pm 50</math></b>  | pA                           |
| $I_{OS}$   | Input Offset Current        |                                          |                    | 5                  |                                          | fA                           |
| CMRR       | Common Mode Rejection Ratio | $0\text{V} \leq V_{CM} \leq 1.5\text{V}$ | 77<br><b>76</b>    | 91                 |                                          | dB                           |

- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.

## 2.5V DC Electrical Characteristics<sup>(1)</sup> (continued)

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 2.5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol    | Parameter                     | Conditions                                                                          | Min <sup>(2)</sup>  | Typ <sup>(3)</sup> | Max <sup>(2)</sup> | Units                     |
|-----------|-------------------------------|-------------------------------------------------------------------------------------|---------------------|--------------------|--------------------|---------------------------|
| PSRR      | Power Supply Rejection Ratio  | $1.6\text{V} \leq V^+ \leq 5.5\text{V}$<br>$V^- = 0\text{V}$ , $V_{CM} = 0\text{V}$ | 83<br><b>83</b>     | 120                |                    | dB                        |
| CMVR      | Common Mode Voltage Range     | CMRR $\geq 77\text{ dB}$<br>CMRR $\geq 76\text{ dB}$                                | -0.2<br><b>-0.2</b> |                    | 1.7<br><b>1.7</b>  | V                         |
| $A_{VOL}$ | Large Signal Voltage Gain     | $V_O = 0.3\text{V}$ to $2.2\text{V}$<br>$R_L = 10\text{ k}\Omega$ to $V^+/2$        | 104<br><b>104</b>   | 120                |                    | dB                        |
| $V_O$     | Output Swing High             | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$       |                     | 12                 | 50<br><b>50</b>    | mV<br>from either<br>rail |
|           | Output Swing Low              | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$      |                     | 13                 | 50<br><b>50</b>    |                           |
| $I_O$     | Output Current <sup>(4)</sup> | Sourcing, $V_O$ to $V^-$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$                   | 5<br><b>4</b>       | 8                  |                    | mA                        |
|           |                               | Sinking, $V_O$ to $V^+$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$                   | 3.5<br><b>2.5</b>   | 7                  |                    |                           |
| $I_S$     | Supply Current                |                                                                                     |                     | 10                 | 14<br><b>15</b>    | $\mu\text{A}$             |

(4) The short circuit test is a momentary open loop test.

## 2.5V AC Electrical Characteristics<sup>(1)</sup>

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 2.5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                            | Conditions                                                     | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup> | Units                        |
|------------|--------------------------------------|----------------------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| GBW        | Gain-Bandwidth Product               | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 128                |                    | kHz                          |
| SR         | Slew Rate                            | $A_V = +1$ , $C_L = 20\text{ pF}$<br>$R_L = 10\text{ k}\Omega$ | Falling Edge       | 58                 |                    | V/ms                         |
|            |                                      |                                                                | Rising Edge        | 48                 |                    |                              |
| $\theta_m$ | Phase Margin                         | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 74                 |                    | deg                          |
| $G_m$      | Gain Margin                          | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 26                 |                    | dB                           |
| $e_n$      | Input-Referred Voltage Noise Density | $f = 1\text{ kHz}$                                             |                    | 60                 |                    | $\text{nV}/\sqrt{\text{Hz}}$ |
|            | Input-Referred Voltage Noise         | 0.1 Hz to 10 Hz                                                |                    | 2.5                |                    | $\mu\text{V}_{PP}$           |
| $i_n$      | Input-Referred Current Noise         | $f = 1\text{ kHz}$                                             |                    | 10                 |                    | $\text{fA}/\sqrt{\text{Hz}}$ |
| THD+N      | Total Harmonic Distortion + Noise    | $f = 100\text{ Hz}$ , $R_L = 10\text{ k}\Omega$                |                    | 0.005              |                    | %                            |

- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.

## 1.8V DC Electrical Characteristics <sup>(1)</sup>

Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 1.8\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                     | Conditions                                                                          | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup>                       | Units                        |
|------------|-------------------------------|-------------------------------------------------------------------------------------|--------------------|--------------------|------------------------------------------|------------------------------|
| $V_{OS}$   | Input Offset Voltage          |                                                                                     |                    | $\pm 10$           | $\pm 230$<br><b><math>\pm 325</math></b> | $\mu\text{V}$                |
| $TCV_{OS}$ | Input Offset Voltage Drift    | LMP2231A                                                                            |                    | $\pm 0.3$          | $\pm 0.4$                                | $\mu\text{V}/^\circ\text{C}$ |
|            |                               | LMP2231B                                                                            |                    | $\pm 0.3$          | $\pm 2.5$                                |                              |
| $I_{BIAS}$ | Input Bias Current            |                                                                                     |                    | 0.02               | $\pm 1.0$<br><b><math>\pm 50</math></b>  | pA                           |
| $I_{OS}$   | Input Offset Current          |                                                                                     |                    | 5                  |                                          | fA                           |
| CMRR       | Common Mode Rejection Ratio   | $0\text{V} \leq V_{CM} \leq 0.8\text{V}$                                            | 76<br><b>75</b>    | 92                 |                                          | dB                           |
| PSRR       | Power Supply Rejection Ratio  | $1.6\text{V} \leq V^+ \leq 5.5\text{V}$<br>$V^- = 0\text{V}$ , $V_{CM} = 0\text{V}$ | 83<br><b>83</b>    | 120                |                                          | dB                           |
| CMVR       | Common Mode Voltage Rang      | CMRR $\geq 76\text{ dB}$<br>CMRR $\geq 75\text{ dB}$                                | -0.2<br><b>0</b>   |                    | 1.0<br><b>1.0</b>                        | V                            |
| $A_{VOL}$  | Large Signal Voltage Gain     | $V_O = 0.3\text{V}$ to $1.5\text{V}$<br>$R_L = 10\text{ k}\Omega$ to $V^+/2$        | 103<br><b>103</b>  | 120                |                                          | dB                           |
| $V_O$      | Output Swing High             | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$       |                    | 12                 | 50<br><b>50</b>                          | mV<br>from either<br>rail    |
|            | Output Swing Low              | $R_L = 10\text{ k}\Omega$ to $V^+/2$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$      |                    | 13                 | 50<br><b>50</b>                          |                              |
| $I_O$      | Output Current <sup>(4)</sup> | Sourcing, $V_O$ to $V^-$<br>$V_{IN}(\text{diff}) = 100\text{ mV}$                   | 2.5<br><b>2</b>    | 5                  |                                          | mA                           |
|            |                               | Sinking, $V_O$ to $V^+$<br>$V_{IN}(\text{diff}) = -100\text{ mV}$                   | 2<br><b>1.5</b>    | 5                  |                                          |                              |
| $I_S$      | Supply Current                |                                                                                     |                    | 10                 | 14<br><b>15</b>                          | $\mu\text{A}$                |

- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.
- (4) The short circuit test is a momentary open loop test.

## 1.8V AC Electrical Characteristics <sup>(1)</sup>

Unless otherwise is specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 1.8\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol     | Parameter                            | Conditions                                                     | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup> | Units                        |
|------------|--------------------------------------|----------------------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| GBW        | Gain-Bandwidth Product               | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 127                |                    | kHz                          |
| SR         | Slew Rate                            | $A_V = +1$ , $C_L = 20\text{ pF}$<br>$R_L = 10\text{ k}\Omega$ | Falling Edge       | 58                 |                    | V/ms                         |
|            |                                      |                                                                | Rising Edge        | 48                 |                    |                              |
| $\theta_m$ | Phase Margin                         | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 70                 |                    | deg                          |
| $G_m$      | Gain Margin                          | $C_L = 20\text{ pF}$ , $R_L = 10\text{ k}\Omega$               |                    | 25                 |                    | dB                           |
| $e_n$      | Input-Referred Voltage Noise Density | $f = 1\text{ kHz}$                                             |                    | 60                 |                    | $\text{nV}/\sqrt{\text{Hz}}$ |
|            | Input-Referred Voltage Noise         | 0.1 Hz to 10 Hz                                                |                    | 2.4                |                    | $\mu\text{V}_{PP}$           |

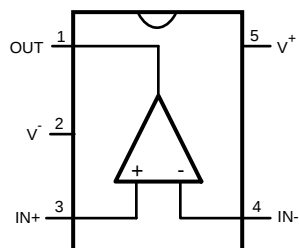
- (1) Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that  $T_J = T_A$ . No ensured specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ . Absolute Maximum Ratings indicate junction temperature limits beyond which the device may be permanently degraded, either mechanically or electrically.
- (2) All limits are specified by testing, statistical analysis or design.
- (3) Typical values represent the most likely parametric norm at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not ensured on shipped production material.

## 1.8V AC Electrical Characteristics<sup>(1)</sup> (continued)

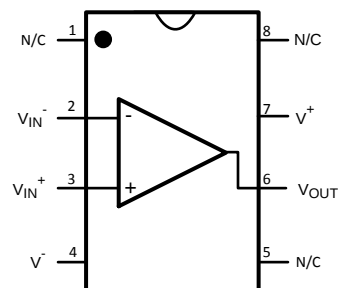
Unless otherwise is specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V^+ = 1.8\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = V_O = V^+/2$ , and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

| Symbol | Parameter                         | Conditions                                      | Min <sup>(2)</sup> | Typ <sup>(3)</sup> | Max <sup>(2)</sup> | Units                        |
|--------|-----------------------------------|-------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| $i_n$  | Input-Referred Current Noise      | $f = 1\text{ kHz}$                              |                    | 10                 |                    | $\text{fA}/\sqrt{\text{Hz}}$ |
| THD+N  | Total Harmonic Distortion + Noise | $f = 100\text{ Hz}$ , $R_L = 10\text{ k}\Omega$ |                    | 0.005              |                    | %                            |

## Connection Diagram



**Figure 2. 5-Pin SOT-23 (Top View)**  
See Package Number DBV0005A



**Figure 3. 8-Pin SOIC (Top View)**  
See Package Number D0008A

## Typical Performance Characteristics

Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

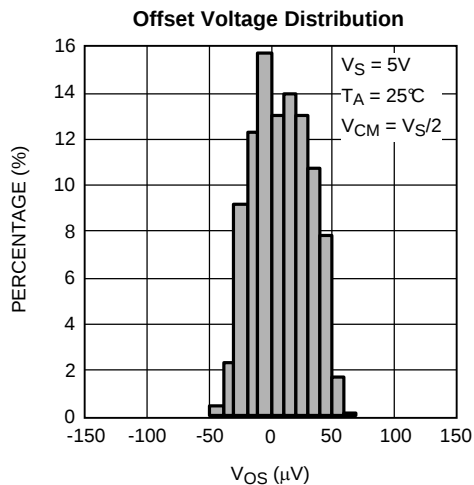


Figure 4.

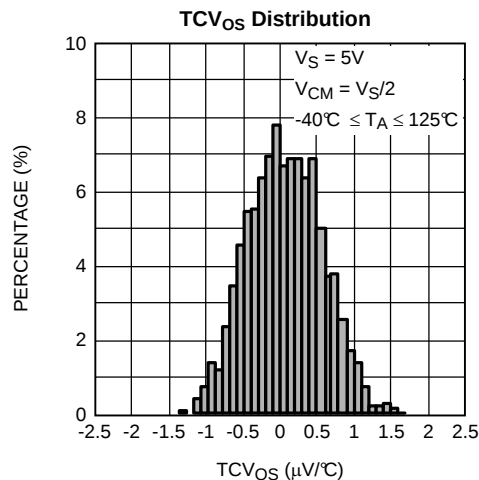


Figure 5.

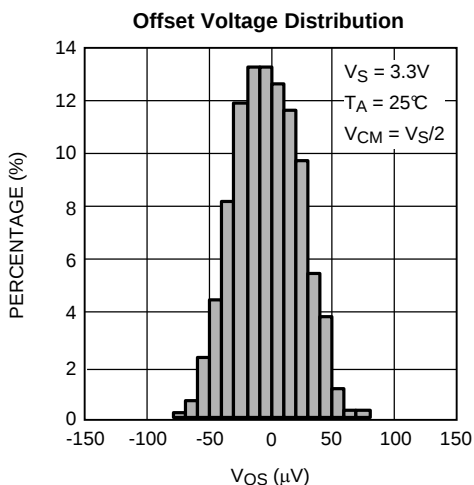


Figure 6.

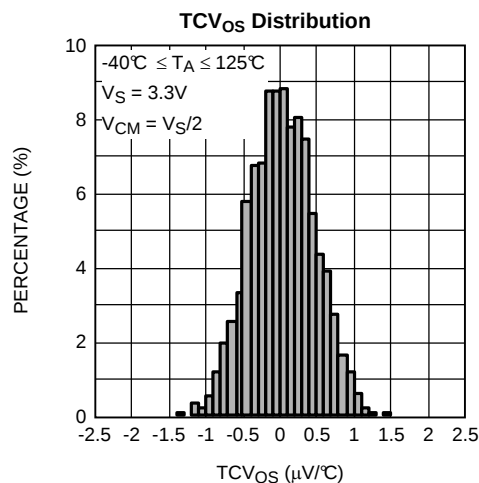


Figure 7.

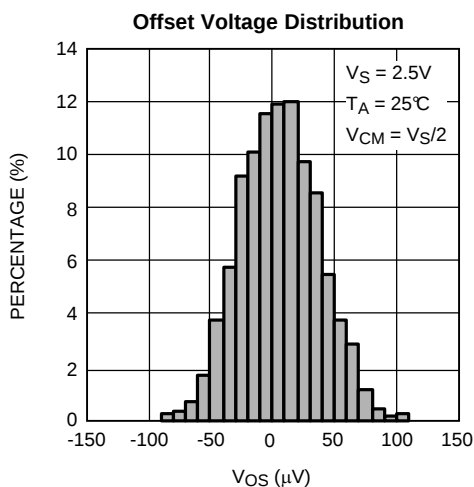


Figure 8.

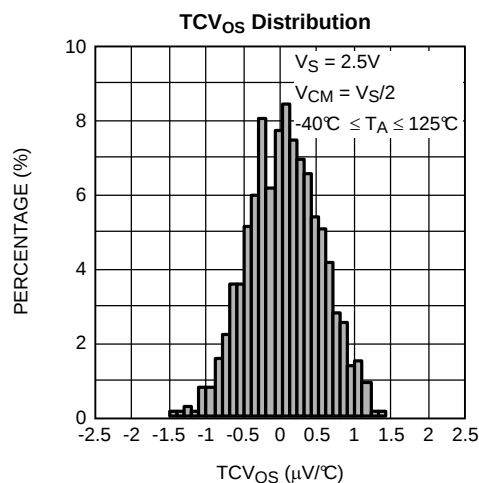


Figure 9.

### Typical Performance Characteristics (continued)

Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

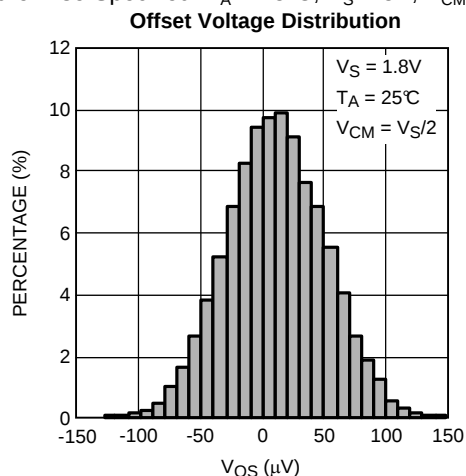


Figure 10.

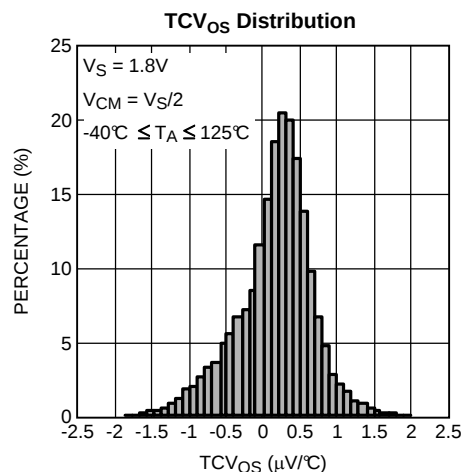


Figure 11.

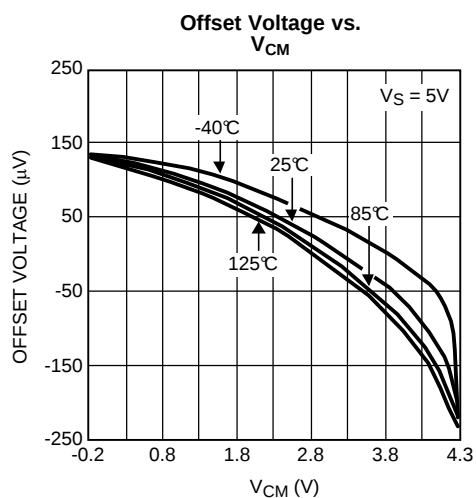


Figure 12.

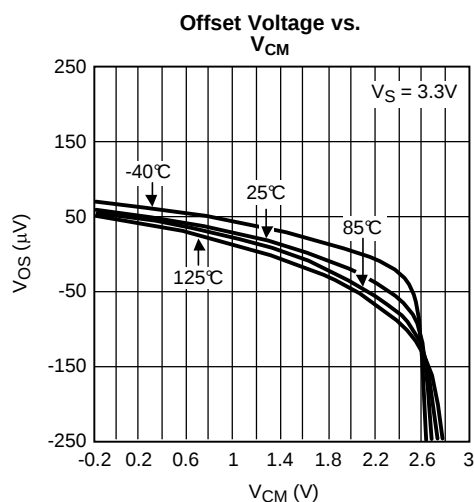


Figure 13.

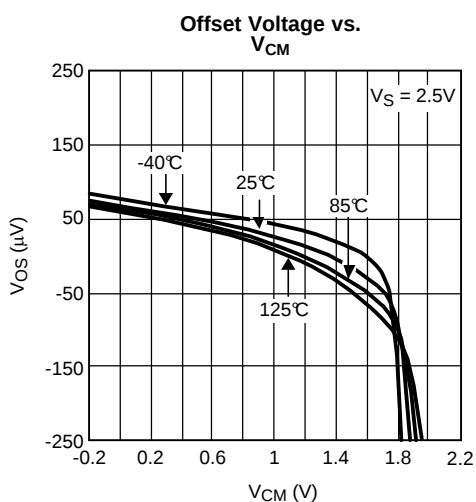


Figure 14.

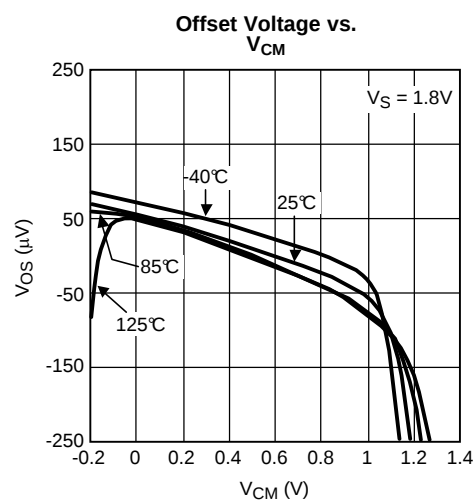


Figure 15.

## Typical Performance Characteristics (continued)

Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

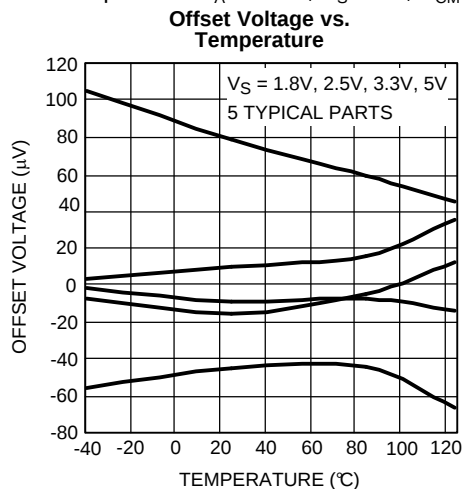


Figure 16.

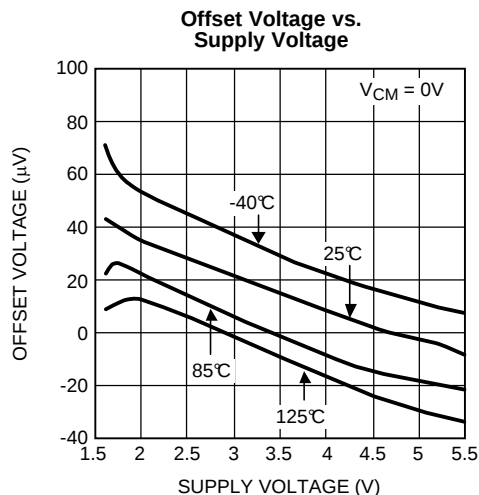


Figure 17.

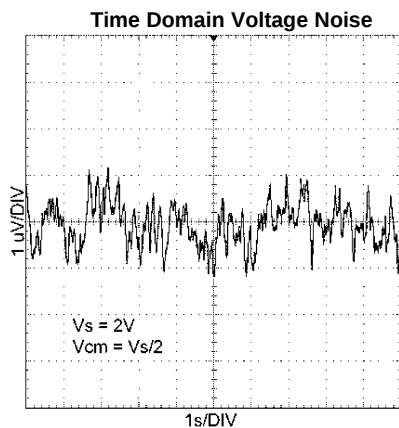


Figure 18.

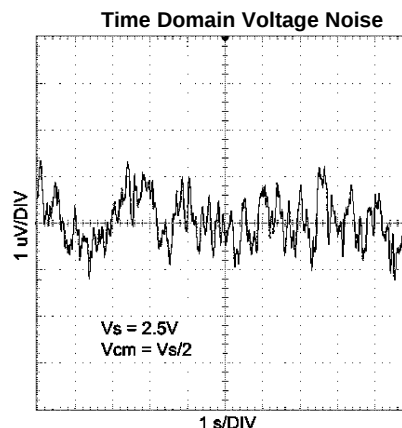


Figure 19.

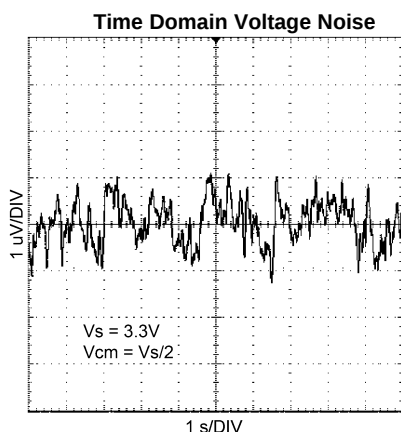


Figure 20.

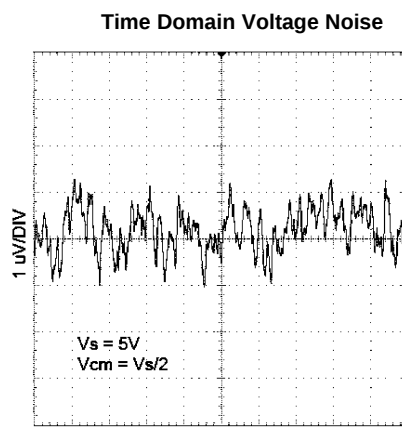


Figure 21.

### Typical Performance Characteristics (continued)

Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

Input Bias Current vs.  
 $V_{CM}$

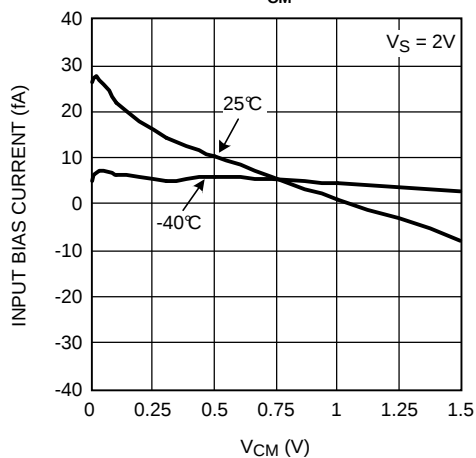


Figure 22.

Input Bias Current vs.  
 $V_{CM}$

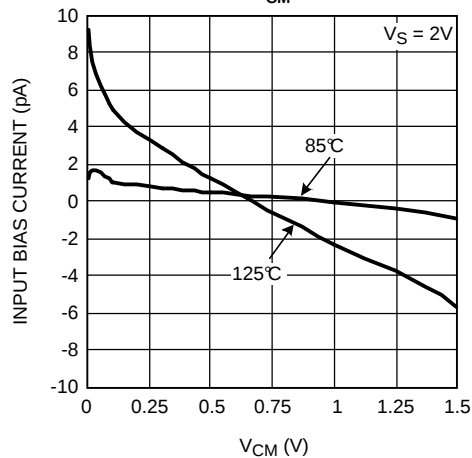


Figure 23.

Input Bias Current vs.  
 $V_{CM}$

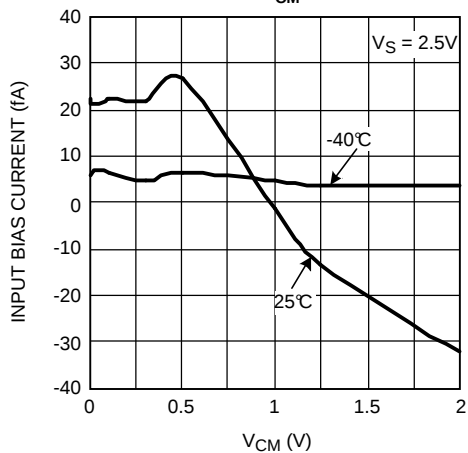


Figure 24.

Input Bias Current vs.  
 $V_{CM}$

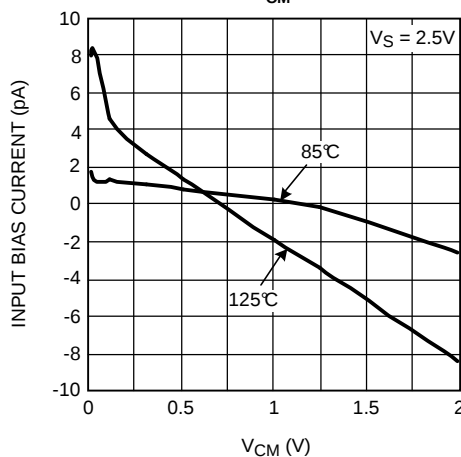


Figure 25.

Input Bias Current vs.  
 $V_{CM}$

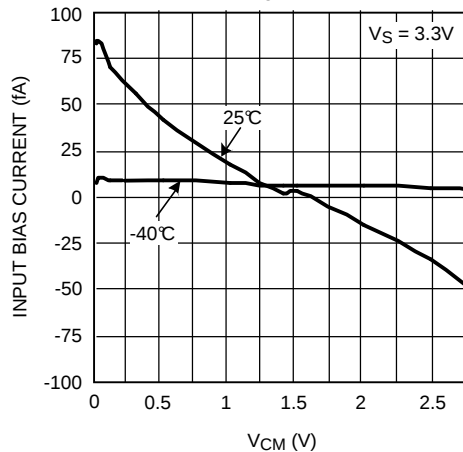


Figure 26.

Input Bias Current vs.  
 $V_{CM}$

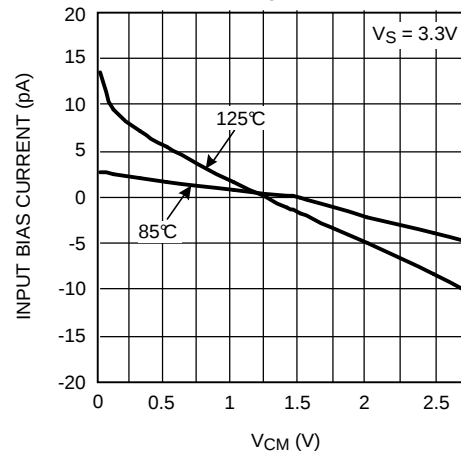


Figure 27.

## Typical Performance Characteristics (continued)

Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

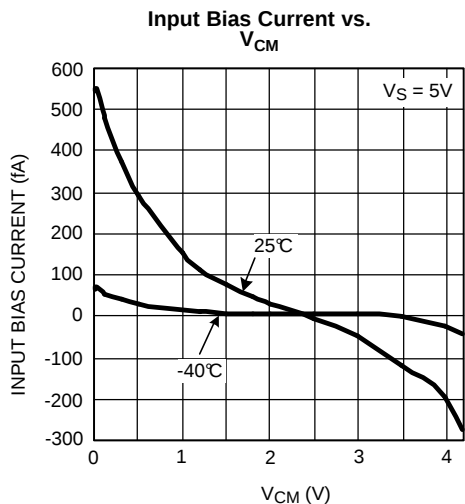


Figure 28.

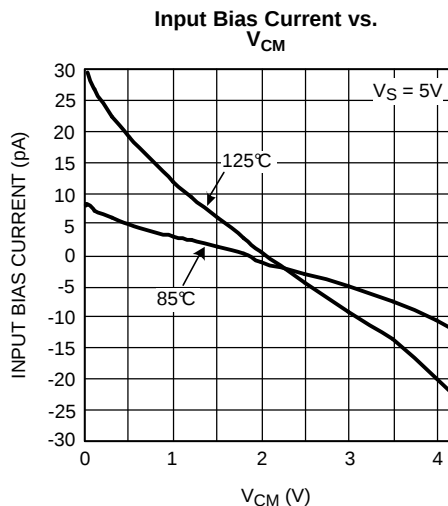


Figure 29.

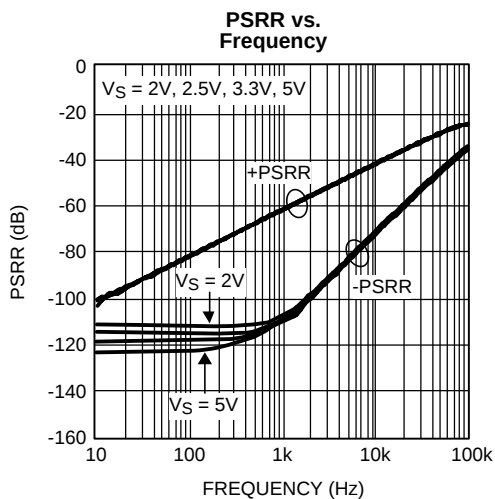


Figure 30.

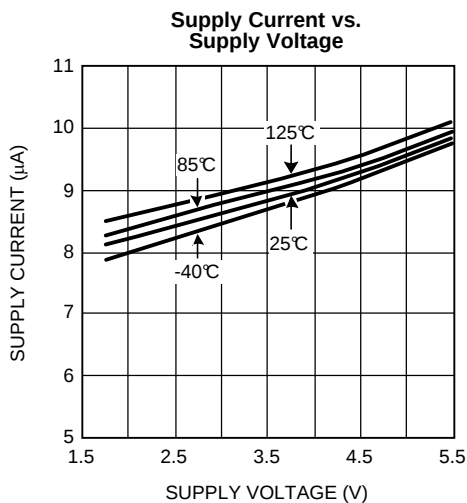
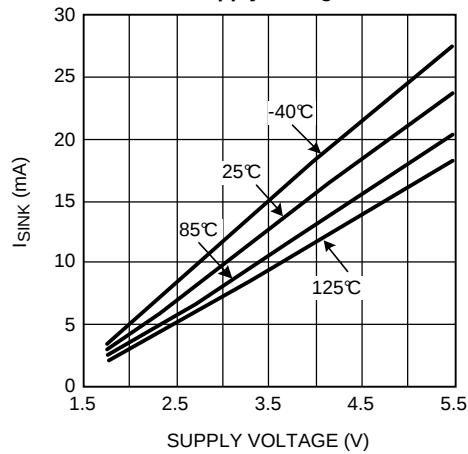


Figure 31.

### Typical Performance Characteristics (continued)

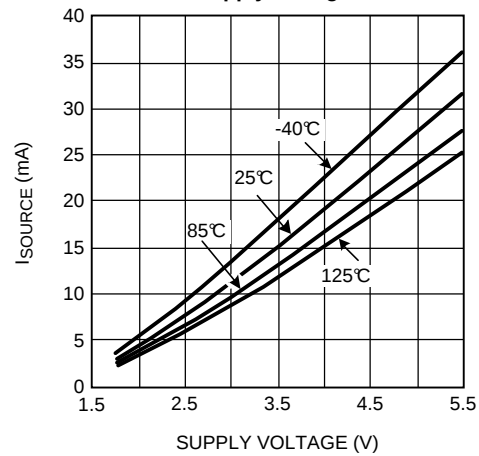
Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

**Sinking Current vs.  
Supply Voltage**



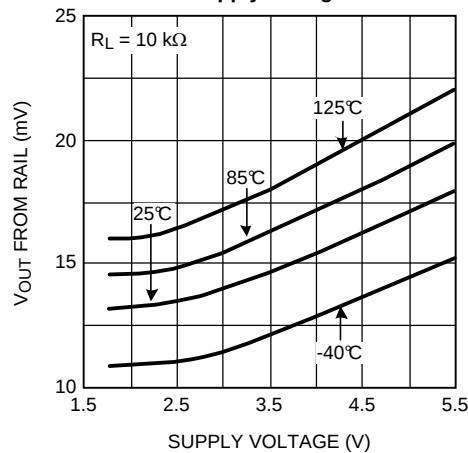
**Figure 32.**

**Sourcing Current vs.  
Supply Voltage**



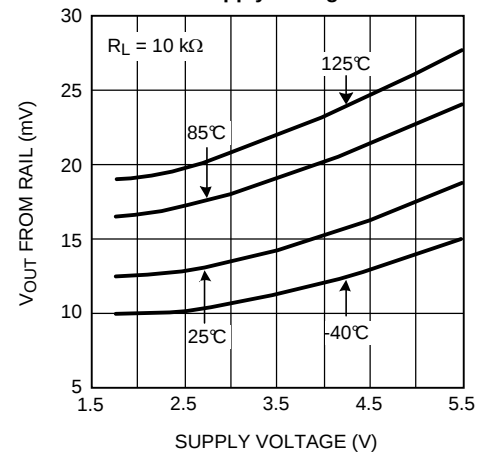
**Figure 33.**

**Output Swing High vs.  
Supply Voltage**



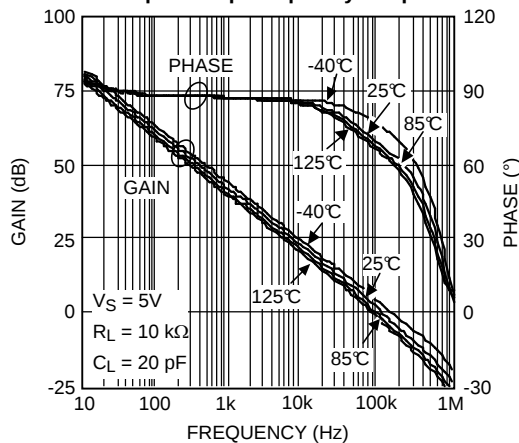
**Figure 34.**

**Output Swing Low vs.  
Supply Voltage**



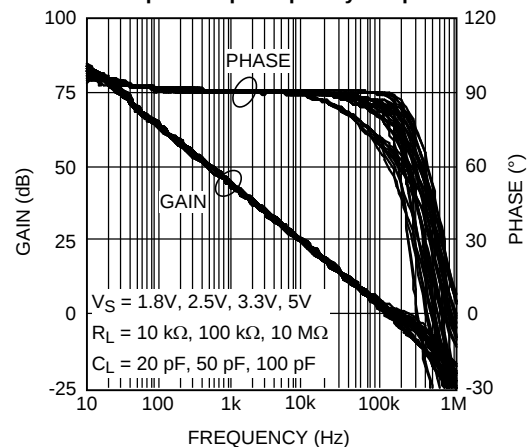
**Figure 35.**

**Open Loop Frequency Response**



**Figure 36.**

**Open Loop Frequency Response**



**Figure 37.**

## Typical Performance Characteristics (continued)

Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

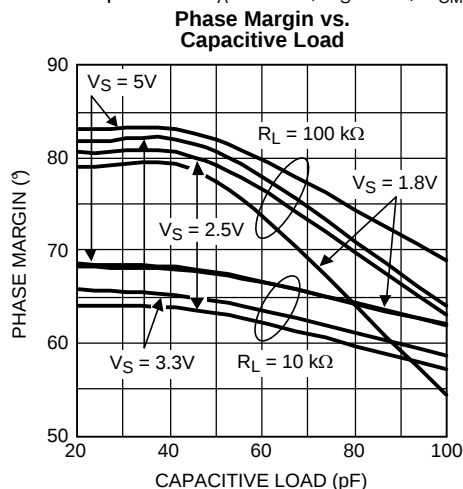


Figure 38.

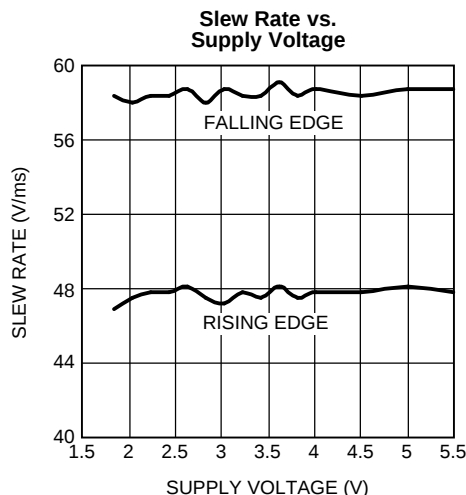


Figure 39.

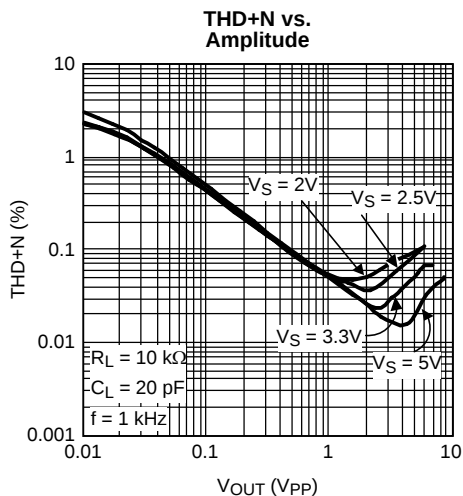


Figure 40.

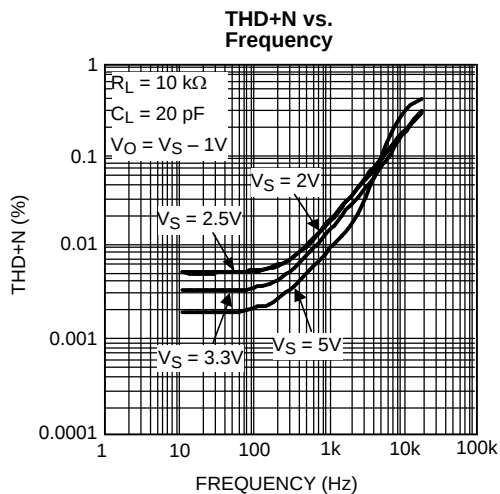


Figure 41.

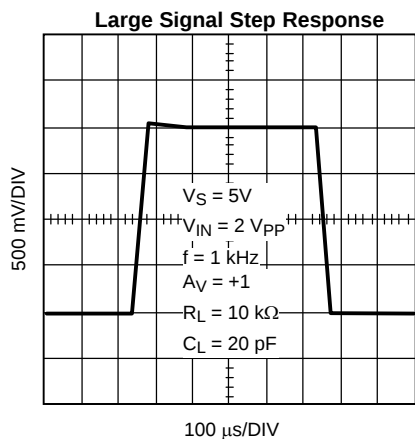


Figure 42.

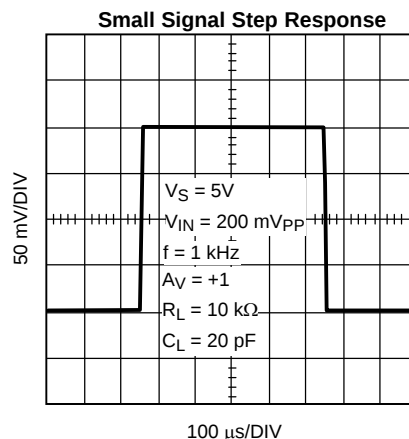


Figure 43.

### Typical Performance Characteristics (continued)

Unless otherwise Specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ , where  $V_S = V^+ - V^-$

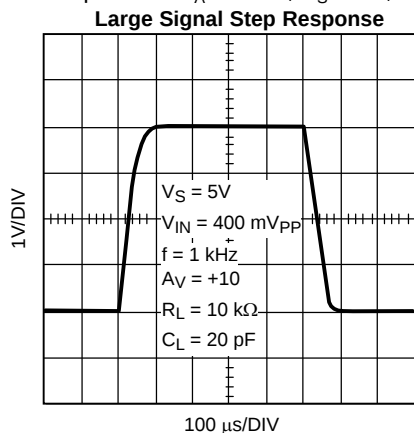


Figure 44.

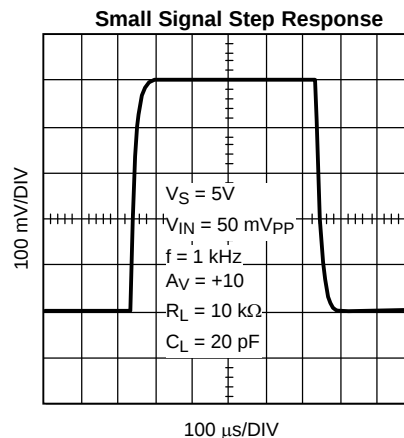


Figure 45.

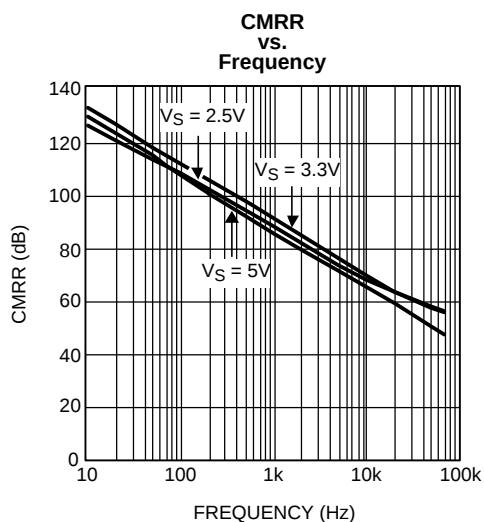


Figure 46.

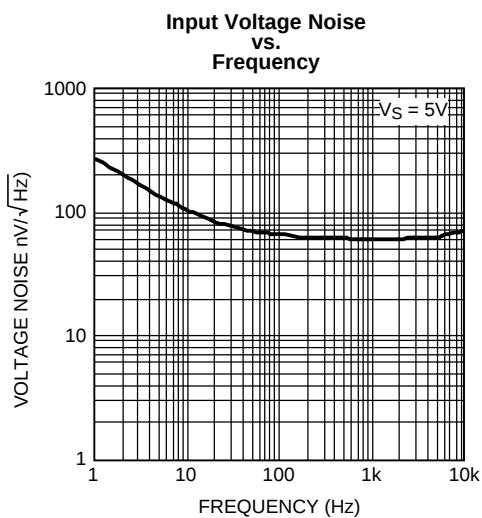


Figure 47.

## APPLICATION INFORMATION

### LMP2231

The LMP2231 is a single CMOS precision amplifier that offer low offset voltage and low offset voltage drift, and high gain while only consuming 10  $\mu\text{A}$  of current per channel.

The LMP2231 is a micropower op amp, consuming only 10  $\mu\text{A}$  of current. Micropower op amps extend the run time of battery powered systems and reduce energy consumption in energy limited systems. The ensured supply voltage range of 1.8V to 5.0V along with the ultra-low supply current extend the battery run time in two ways. The extended ensured power supply voltage range of 1.8V to 5.0V enables the op amp to function when the battery voltage has depleted from its nominal value down to 1.8V. In addition, the lower power consumption increases the life of the battery.

The LMP2231 has an input referred offset voltage of only  $\pm 150 \mu\text{V}$  maximum at room temperature. This offset is ensured to be less than  $\pm 230 \mu\text{V}$  over temperature. This minimal offset voltage along with very low  $\text{TCV}_{\text{OS}}$  of only  $0.3 \mu\text{V}/^\circ\text{C}$  typical allows more accurate signal detection and amplification in precision applications.

The low input bias current of only  $\pm 20 \text{ fA}$  gives the LMP2231 superiority for use in high impedance sensor applications. Bias Current of an amplifier flows through source resistance of the sensor and the voltage resulting from this current flow appears as a noise voltage on the input of the amplifier. The low input bias current enables the LMP2231 to interface with high impedance sensors while generating negligible voltage noise. Thus the LMP2231 provides better signal fidelity and a higher signal-to-noise ration when interfacing with high impedance sensors.

Texas Instruments is heavily committed to precision amplifiers and the market segment they serve. Technical support and extensive characterization data is available for sensitive applications or applications with a constrained error budget.

The operating supply voltage range of 1.8V to 5.5V over the extensive temperature range of  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  makes the LMP2231 an excellent choice for low voltage precision applications with extensive temperature requirements.

The LMP2231 is offered in the space saving 5-Pin SOT-23 and 8-pin SOIC package. These small packages are ideal solutions for area constrained PC boards and portable electronics.

### TOTAL NOISE CONTRIBUTION

The LMP2231 has a very low input bias current, very low input current noise, and low input voltage noise for micropower amplifier. As a result, this amplifier makes a great choice for circuits with high impedance sensor applications.

[Figure 48](#) shows the typical input noise of the LMP2231 as a function of source resistance where:

$e_n$  denotes the input referred voltage noise

$e_i$  is the voltage drop across source resistance due to input referred current noise or  $e_i = R_S * i_n$

$e_t$  shows the thermal noise of the source resistance

$e_{ni}$  shows the total noise on the input.

Where:

$$e_{ni} = \sqrt{e_n^2 + e_i^2 + e_t^2}$$

The input current noise of the LMP2231 is so low that it will not become the dominant factor in the total noise unless source resistance exceeds  $300 \text{ M}\Omega$ , which is an unrealistically high value. As is evident in [Figure 48](#), at lower  $R_S$  values, total noise is dominated by the amplifier's input voltage noise. Once  $R_S$  is larger than a  $100 \text{ k}\Omega$ , then the dominant noise factor becomes the thermal noise of  $R_S$ . As mentioned before, the current noise will not be the dominant noise factor for any practical application.

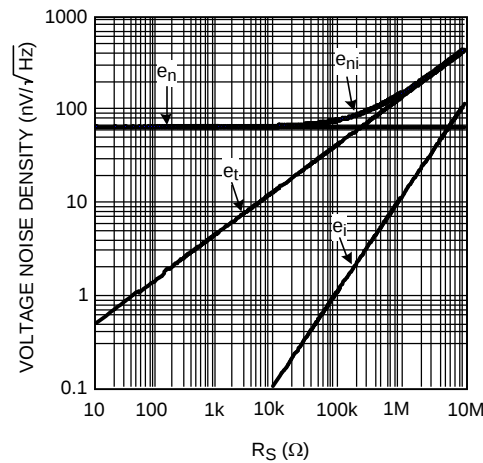


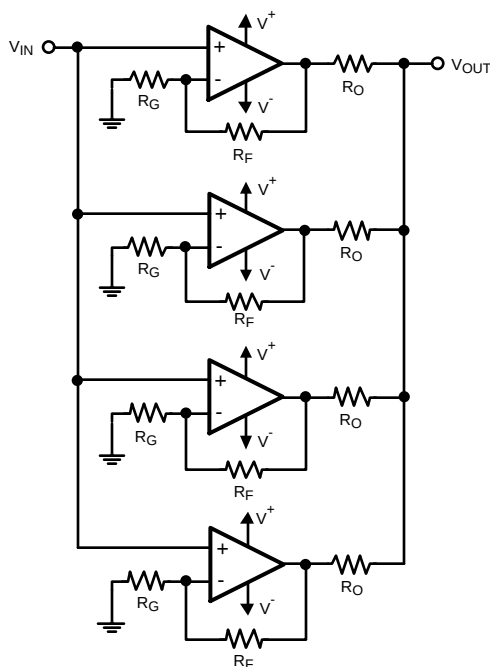
Figure 48. Total Input Noise

### VOLTAGE NOISE REDUCTION

The LMP2231 has an input voltage noise of  $60 \text{ nV}/\sqrt{\text{Hz}}$ . While this value is very low for micropower amplifiers, this input voltage noise can be further reduced by placing  $N$  amplifiers in parallel as shown in Figure 49. The total voltage noise on the output of this circuit is divided by the square root of the number of amplifiers used in this parallel combination. This is because each individual amplifier acts as an independent noise source, and the average noise of independent sources is the quadrature sum of the independent sources divided by the number of sources. For  $N$  identical amplifiers, this means:

$$\begin{aligned}
 \text{REDUCED INPUT VOLTAGE NOISE} &= \frac{1}{N} \sqrt{e_{n1}^2 + e_{n2}^2 + \dots + e_{nN}^2} \\
 &= \frac{1}{N} \sqrt{N e_n^2} = \frac{\sqrt{N}}{N} e_n \\
 &= \frac{1}{\sqrt{N}} e_n
 \end{aligned}$$

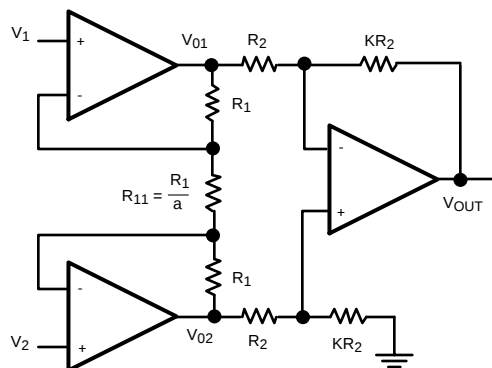
Figure 49 shows a schematic of this input voltage noise reduction circuit. Typical resistor values are:  $R_G = 10\Omega$ ,  $R_F = 1 \text{ k}\Omega$ , and  $R_O = 1 \text{ k}\Omega$ .



**Figure 49. Noise Reduction Circuit**

## PRECISION INSTRUMENTATION AMPLIFIER

Measurement of very small signals with an amplifier requires close attention to the input impedance of the amplifier, gain of the overall signal on the inputs, and the gain on each input of the amplifier. This is because the difference of the input signal on the two inputs is of the interest and the common signal is considered noise. A classic circuit implementation is an instrumentation amplifier. Instrumentation amplifiers have a finite, accurate, and stable gain. They also have extremely high input impedances and very low output impedances. Finally they have an extremely high CMRR so that the amplifier can only respond to the differential signal. A typical instrumentation amplifier is shown in Figure 50.



**Figure 50. Instrumentation Amplifier**

There are two stages in this amplifier. The last stage, output stage, is a differential amplifier. In an ideal case the two amplifiers of the first stage, input stage, would be set up as buffers to isolate the inputs. However they cannot be connected as followers because of mismatch of amplifiers. That is why there is a balancing resistor between the two. The product of the two stages of gain will give the gain of the instrumentation amplifier. Ideally, the CMRR should be infinite. However the output stage has a small non-zero common mode gain which results from resistor mismatch.

In the input stage of the circuit, current is the same across all resistors. This is due to the high input impedance and low input bias current of the LMP2231.

$$\text{GIVEN: } I_{R_1} = I_{R_{11}} \quad (1)$$

By Ohm's Law:

$$\begin{aligned} V_{O1} - V_{O2} &= (2R_1 + R_{11}) I_{R_{11}} \\ &= (2a + 1) R_{11} \cdot I_{R_{11}} \\ &= (2a + 1) V_{R_{11}} \end{aligned} \quad (2)$$

However:

$$V_{R_{11}} = V_1 - V_2 \quad (3)$$

So we have:

$$V_{O1} - V_{O2} = (2a + 1)(V_1 - V_2) \quad (4)$$

Now looking at the output of the instrumentation amplifier:

$$\begin{aligned} V_O &= \frac{KR_2}{R_2} (V_{O2} - V_{O1}) \\ &= -K (V_{O1} - V_{O2}) \end{aligned} \quad (5)$$

Substituting from [Equation 4](#):

$$V_O = -K (2a + 1) (V_1 - V_2) \quad (6)$$

This shows the gain of the instrumentation amplifier to be:

$$-K(2a + 1) \quad (7)$$

Typical values for this circuit can be obtained by setting:  $a = 12$  and  $K = 4$ . This results in an overall gain of  $-100$ .

## SINGLE SUPPLY STRAIN GAGE BRIDGE AMPLIFIER

Strain gauges are popular electrical elements used to measure force or pressure. Strain gauges are subjected to an unknown force which is measured as a the deflection on a previously calibrated scale. Pressure is often measured using the same technique; however this pressure needs to be converted into force using an appropriate transducer. Strain gauges are often resistors which are sensitive to pressure or to flexing. Sense resistor values range from tens of ohms to several hundred kilo ohms. The resistance change which is a result of applied force across the strain gauge might be 1% of its total value. An accurate and reliable system is needed to measure this small resistance change. Bridge configurations offer a reliable method for this measurement.

Bridge sensors are formed of four resistors, connected as a quadrilateral. A voltage source or a current source is used across one of the diagonals to excite the bridge while a voltage detector across the other diagonal measures the output voltage.

Bridges are mainly used as null circuits or to measure a differential voltages. Bridges will have no output voltage if the ratios of two adjacent resistor values are equal. This fact is used in null circuit measurements. These are particularly used in feedback systems which involve electrochemical elements or human interfaces. Null systems force an active resistor, such as a strain gauge, to balance the bridge by influencing the measured parameter.

Often in sensor applications at least one of the resistors is a variable resistor, or a sensor. The deviation of this active element from its initial value is measured as an indication of change in the measured quantity. A change in output voltage represents the sensor value change. Since the sensor value change is often very small, the resulting output voltage is very small in magnitude as well. This requires an extensive and very precise amplification circuitry so that signal fidelity does not change after amplification.

Sensitivity of a bridge is the ratio of its maximum expected output change to the excitation voltage change.

Figure 51 (a) shows a typical bridge sensor and Figure 51(b) shows the bridge with four sensors. R in Figure 51(b) is the nominal value of the sense resistor and the deviations from R are proportional to the quantity being measured.

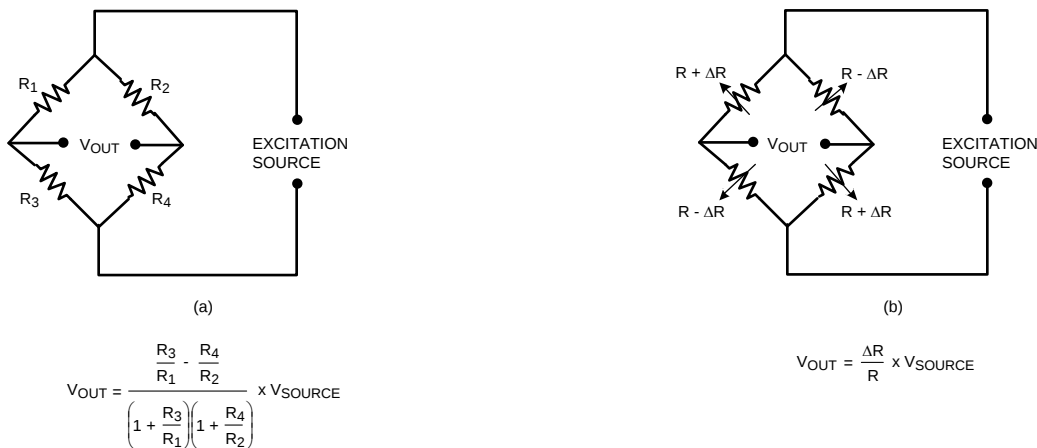


Figure 51. Bridge Sensor

Instrumentation amplifiers are great for interfacing with bridge sensors. Bridge sensors often sense a very small differential signal in the presence of a larger common mode voltage. Instrumentation amplifiers reject this common mode signal.

Figure 52 shows a strain gauge bridge amplifier. In this application the LMP2231 is used to buffer the LM4140's precision output voltage. The LM4140A is a precision voltage reference. The other three LMP2231s are used to form an instrumentation amplifier. This instrumentation amplifier uses the LMP2231's high CMRR and low  $V_{OS}$  and  $TCV_{OS}$  to accurately amplify the small differential signal generated by the output of the bridge sensor. This amplified signal is then fed into the ADC121S021 which is a 12-bit analog to digital converter. This circuit works on a single supply voltage of 5V.

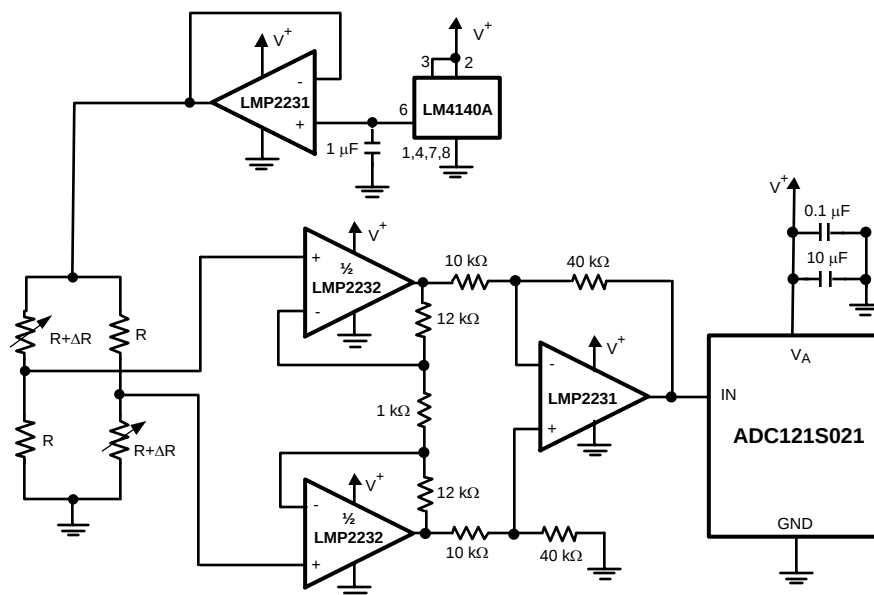


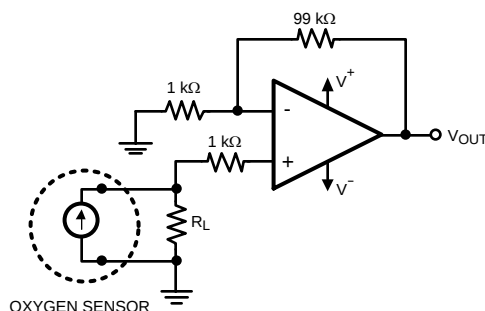
Figure 52. Strain Gauge Bridge Amplifier

## PORTABLE GAS DETECTION SENSOR

Gas sensors are used in many different industrial and medical applications. They generate a current which is proportional to the percentage of a particular gas sensed in an air sample. This current goes through a load resistor and the resulting voltage drop is measured. Depending on the sensed gas and sensitivity of the sensor, the output current can be in the order of tens of microamperes to a few milliamperes. Gas sensor datasheets often specify a recommended load resistor value or they suggest a range of load resistors to choose from.

Oxygen sensors are used when air quality or oxygen delivered to a patient needs to be monitored. Fresh air contains 20.9% oxygen. Air samples containing less than 18% oxygen are considered dangerous. Oxygen sensors are also used in industrial applications where the environment must lack oxygen. An example is when food is vacuum packed. There are two main categories of oxygen sensors, those which sense oxygen when it is abundantly present (i.e. in air or near an oxygen tank) and those which detect traces of oxygen in ppm.

Figure 53 shows a typical circuit used to amplify the output of an oxygen detector. The LMP2231 makes an excellent choice for this application as it only draws 10  $\mu\text{A}$  of current and operates on supply voltages down to 1.8V. This application detects oxygen in air. The oxygen sensor outputs a known current through the load resistor. This value changes with the amount of oxygen present in the air sample. Oxygen sensors usually recommend a particular load resistor value or specify a range of acceptable values for the load resistor. Oxygen sensors typically have a life of one to two years. The use of the micropower LMP2231 means minimal power usage by the op amp and it enhances the battery life. Depending on other components present in the circuit design, the battery could last for the entire life of the oxygen sensor. The precision specifications of the LMP2231, such as its very low offset voltage, low  $\text{TCV}_{\text{OS}}$ , low input bias current, low CMRR, and low PSRR are other factors which make the LMP2231 a great choice for this application.



**Figure 53. Precision Oxygen Sensor**

## REVISION HISTORY

| Changes from Revision D (March 2013) to Revision E         | Page               |
|------------------------------------------------------------|--------------------|
| • Changed layout of National Data Sheet to TI format ..... | <a href="#">22</a> |

## PACKAGING INFORMATION

| Orderable part number            | Status<br>(1) | Material type<br>(2) | Package   Pins   | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|----------------------------------|---------------|----------------------|------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">LMP2231AMA/NOPB</a>  | Active        | Production           | SOIC (D)   8     | 95   TUBE             | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31AMA      |
| LMP2231AMA/NOPB.A                | Active        | Production           | SOIC (D)   8     | 95   TUBE             | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31AMA      |
| <a href="#">LMP2231AMAE/NOPB</a> | Active        | Production           | SOIC (D)   8     | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31AMA      |
| LMP2231AMAE/NOPB.A               | Active        | Production           | SOIC (D)   8     | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31AMA      |
| <a href="#">LMP2231AMAX/NOPB</a> | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31AMA      |
| LMP2231AMAX/NOPB.A               | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31AMA      |
| <a href="#">LMP2231AMF/NOPB</a>  | Active        | Production           | SOT-23 (DBV)   5 | 1000   SMALL T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5A                |
| LMP2231AMF/NOPB.A                | Active        | Production           | SOT-23 (DBV)   5 | 1000   SMALL T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5A                |
| <a href="#">LMP2231AMFE/NOPB</a> | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5A                |
| LMP2231AMFE/NOPB.A               | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5A                |
| <a href="#">LMP2231AMFX/NOPB</a> | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5A                |
| LMP2231AMFX/NOPB.A               | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5A                |
| <a href="#">LMP2231BMA/NOPB</a>  | Active        | Production           | SOIC (D)   8     | 95   TUBE             | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31BMA      |
| LMP2231BMA/NOPB.A                | Active        | Production           | SOIC (D)   8     | 95   TUBE             | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31BMA      |
| <a href="#">LMP2231BMAE/NOPB</a> | Active        | Production           | SOIC (D)   8     | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31BMA      |
| LMP2231BMAE/NOPB.A               | Active        | Production           | SOIC (D)   8     | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | LMP22<br>31BMA      |
| <a href="#">LMP2231BMF/NOPB</a>  | Active        | Production           | SOT-23 (DBV)   5 | 1000   SMALL T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5B                |
| LMP2231BMF/NOPB.A                | Active        | Production           | SOT-23 (DBV)   5 | 1000   SMALL T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5B                |
| <a href="#">LMP2231BMFE/NOPB</a> | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5B                |
| LMP2231BMFE/NOPB.A               | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5B                |
| <a href="#">LMP2231BMFX/NOPB</a> | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5B                |
| LMP2231BMFX/NOPB.A               | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | SN                                   | Level-1-260C-UNLIM                | -40 to 125   | AL5B                |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

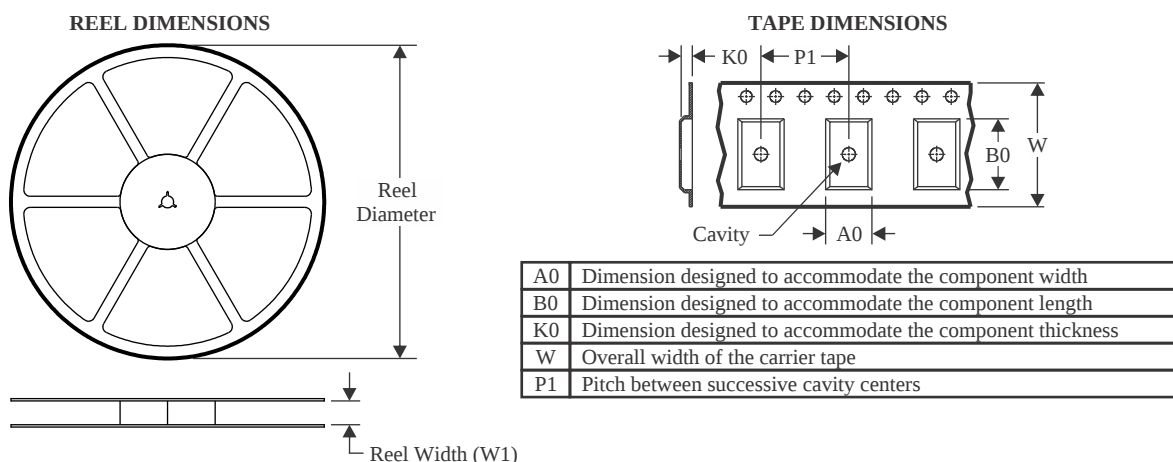
<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

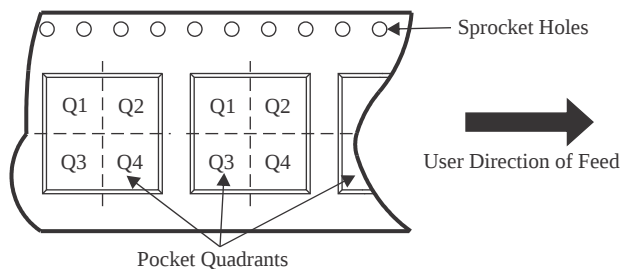
**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

## TAPE AND REEL INFORMATION



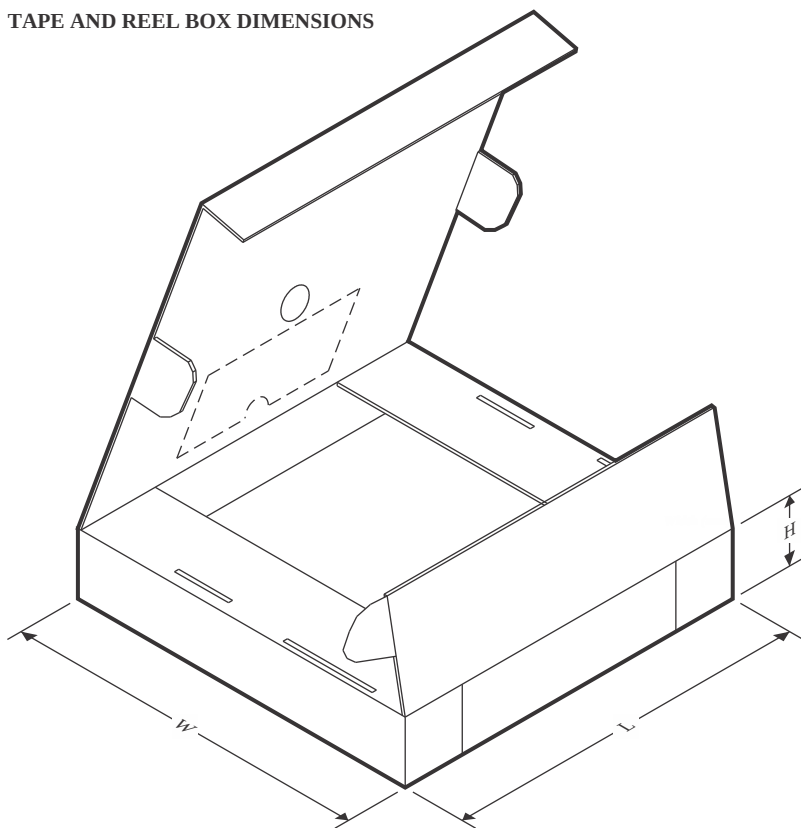
### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



\*All dimensions are nominal

| Device           | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| LMP2231AMAE/NOPB | SOIC         | D               | 8    | 250  | 177.8              | 12.4               | 6.5     | 5.4     | 2.0     | 8.0     | 12.0   | Q1            |
| LMP2231AMAX/NOPB | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.5     | 5.4     | 2.0     | 8.0     | 12.0   | Q1            |
| LMP2231AMF/NOPB  | SOT-23       | DBV             | 5    | 1000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP2231AMFE/NOPB | SOT-23       | DBV             | 5    | 250  | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP2231AMFX/NOPB | SOT-23       | DBV             | 5    | 3000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP2231BMAE/NOPB | SOIC         | D               | 8    | 250  | 177.8              | 12.4               | 6.5     | 5.4     | 2.0     | 8.0     | 12.0   | Q1            |
| LMP2231BMF/NOPB  | SOT-23       | DBV             | 5    | 1000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP2231BMFE/NOPB | SOT-23       | DBV             | 5    | 250  | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP2231BMFX/NOPB | SOT-23       | DBV             | 5    | 3000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |

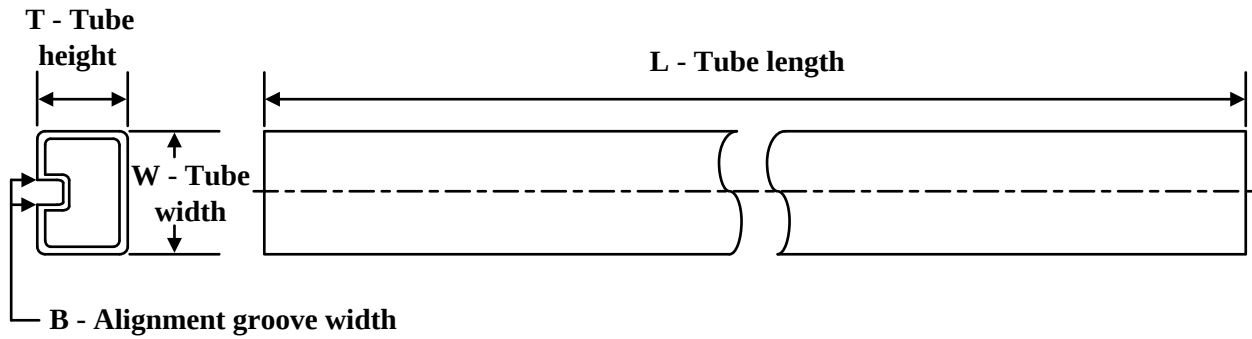
## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

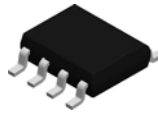
| Device           | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| LMP2231AMAE/NOPB | SOIC         | D               | 8    | 250  | 208.0       | 191.0      | 35.0        |
| LMP2231AMAX/NOPB | SOIC         | D               | 8    | 2500 | 356.0       | 356.0      | 35.0        |
| LMP2231AMF/NOPB  | SOT-23       | DBV             | 5    | 1000 | 208.0       | 191.0      | 35.0        |
| LMP2231AMFE/NOPB | SOT-23       | DBV             | 5    | 250  | 208.0       | 191.0      | 35.0        |
| LMP2231AMFX/NOPB | SOT-23       | DBV             | 5    | 3000 | 208.0       | 191.0      | 35.0        |
| LMP2231BMAE/NOPB | SOIC         | D               | 8    | 250  | 208.0       | 191.0      | 35.0        |
| LMP2231BMF/NOPB  | SOT-23       | DBV             | 5    | 1000 | 208.0       | 191.0      | 35.0        |
| LMP2231BMFE/NOPB | SOT-23       | DBV             | 5    | 250  | 208.0       | 191.0      | 35.0        |
| LMP2231BMFX/NOPB | SOT-23       | DBV             | 5    | 3000 | 208.0       | 191.0      | 35.0        |

## TUBE



\*All dimensions are nominal

| Device            | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (μm) | B (mm) |
|-------------------|--------------|--------------|------|-----|--------|--------|--------|--------|
| LMP2231AMA/NOPB   | D            | SOIC         | 8    | 95  | 495    | 8      | 4064   | 3.05   |
| LMP2231AMA/NOPB.A | D            | SOIC         | 8    | 95  | 495    | 8      | 4064   | 3.05   |
| LMP2231BMA/NOPB   | D            | SOIC         | 8    | 95  | 495    | 8      | 4064   | 3.05   |
| LMP2231BMA/NOPB.A | D            | SOIC         | 8    | 95  | 495    | 8      | 4064   | 3.05   |

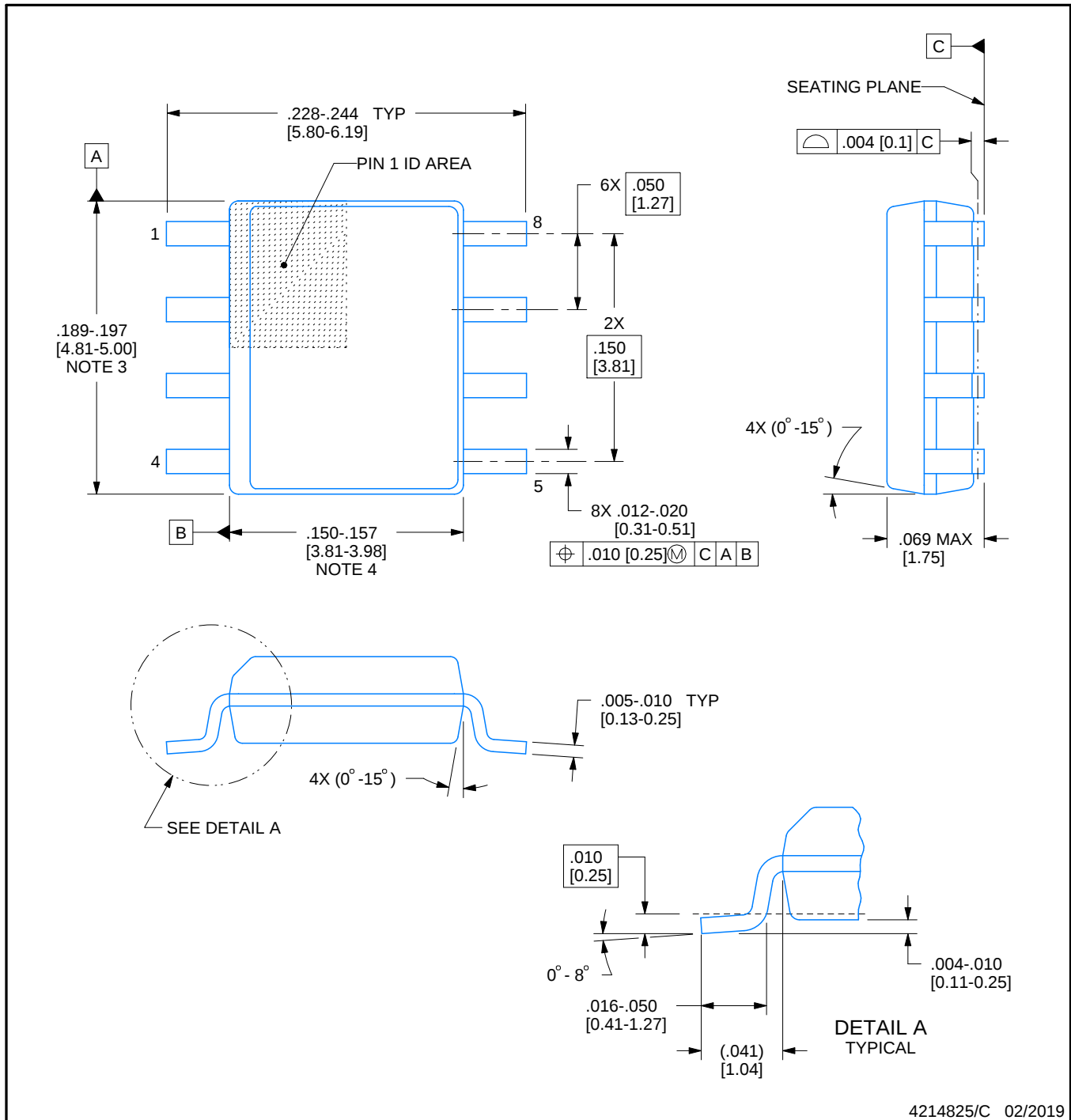


**D0008A**

# PACKAGE OUTLINE

**SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

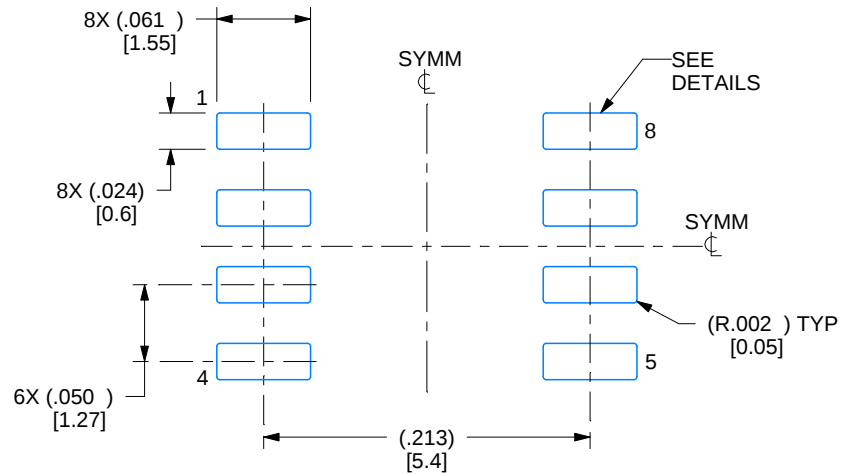
## NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.

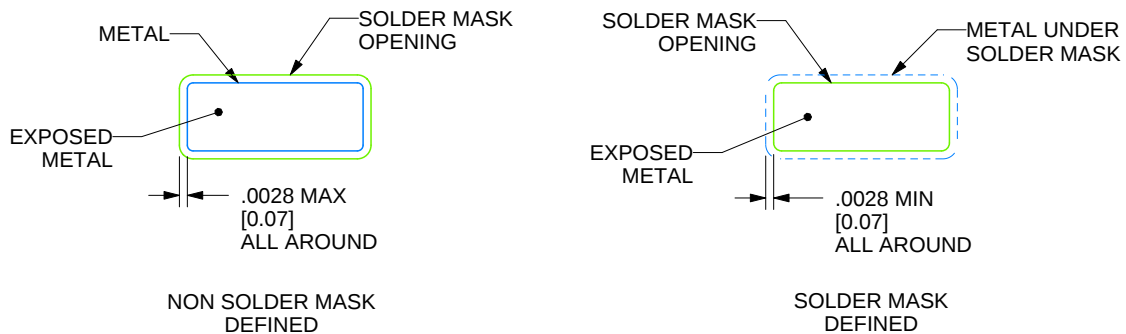
**D0008A**

**SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:8X



## SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

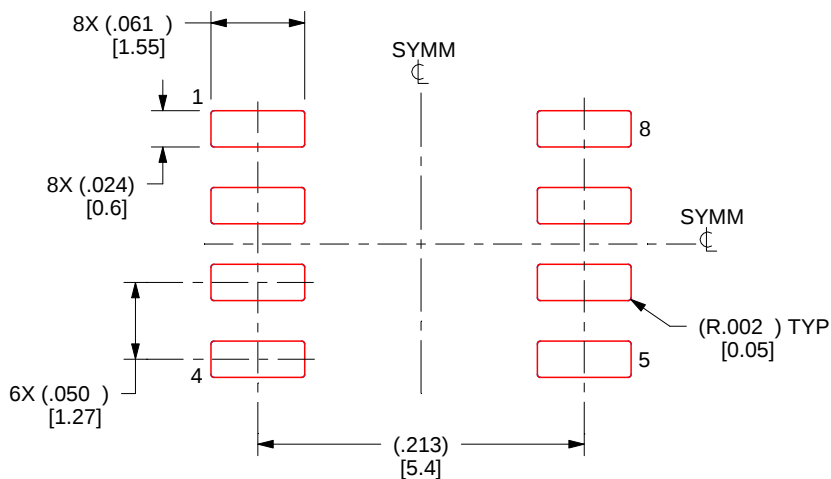
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

## EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE  
BASED ON .005 INCH [0.125 MM] THICK STENCIL  
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

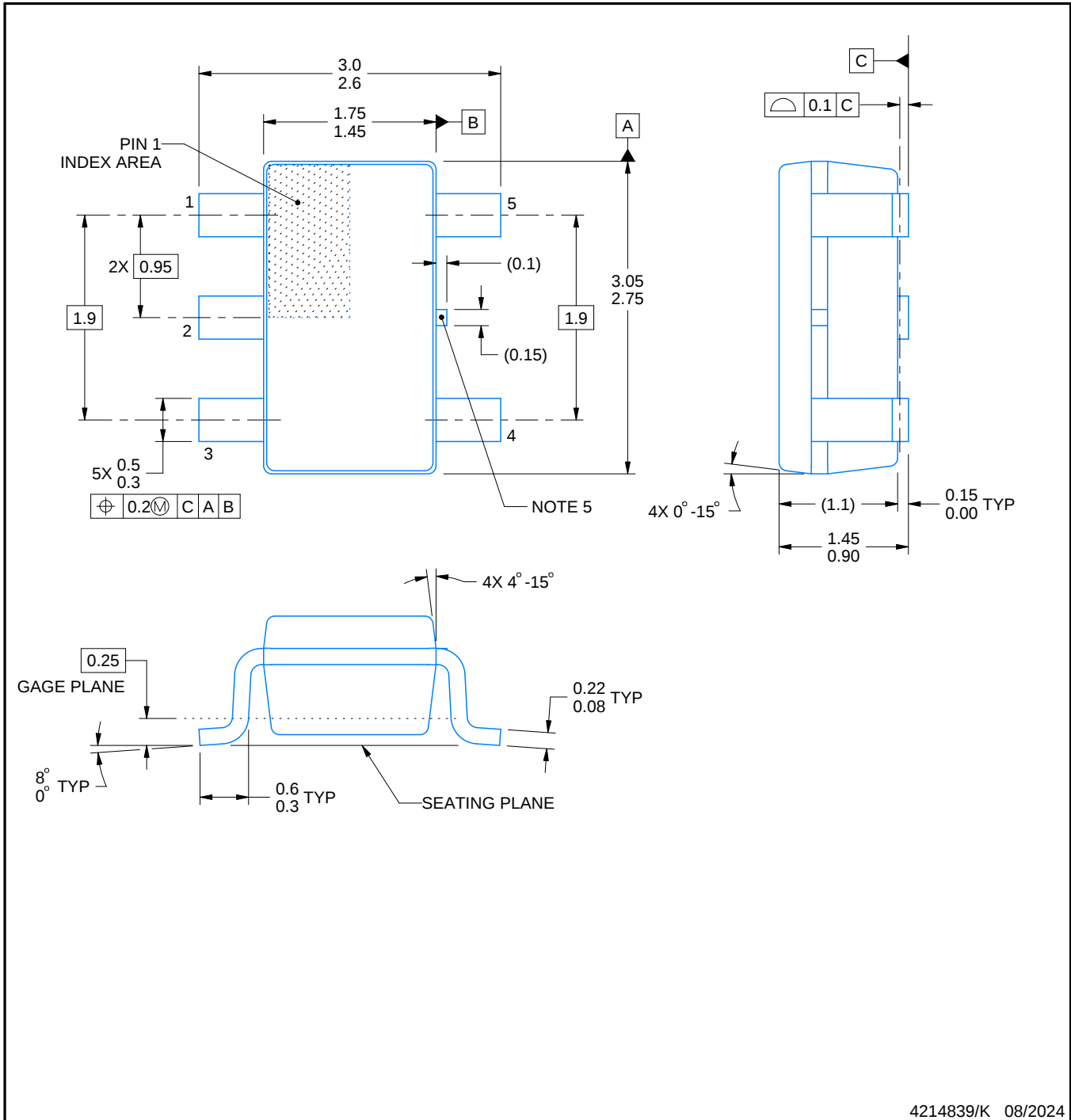


**DBV0005A**

# PACKAGE OUTLINE

**SOT-23 - 1.45 mm max height**

SMALL OUTLINE TRANSISTOR



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## NOTES:

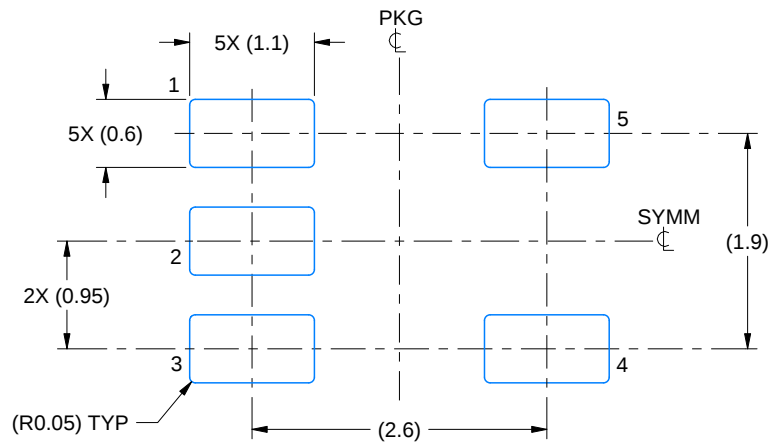
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC MO-178.
4. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25 mm per side.
5. Support pin may differ or may not be present.

# EXAMPLE BOARD LAYOUT

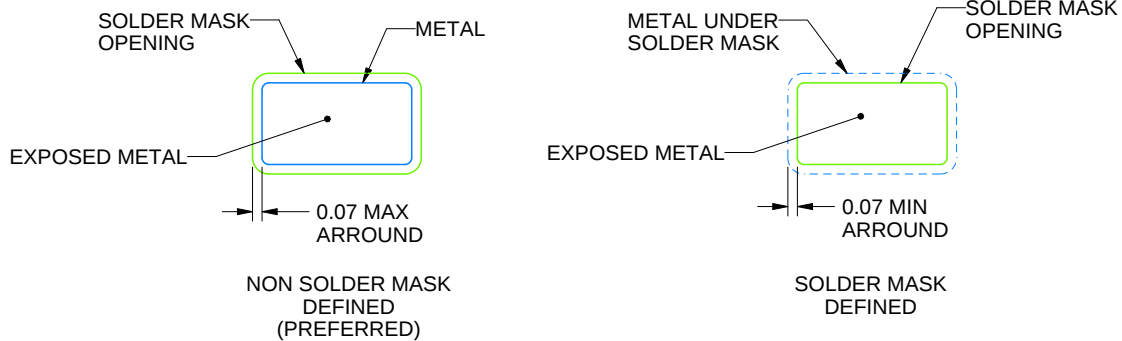
DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:15X



SOLDER MASK DETAILS

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NOTES: (continued)

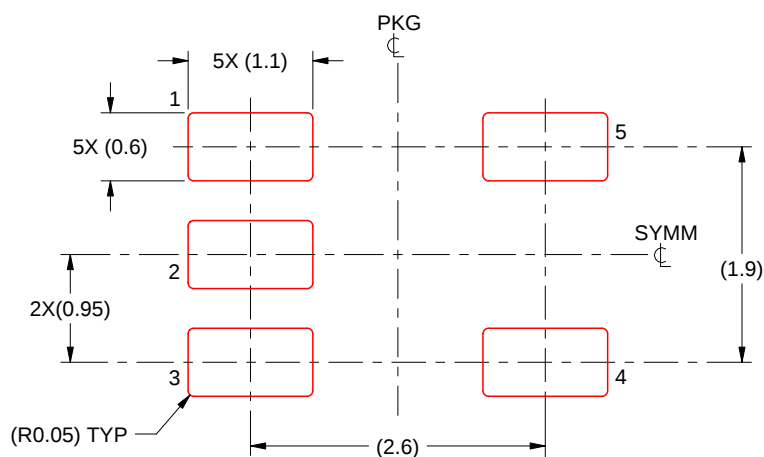
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

## EXAMPLE STENCIL DESIGN

DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL  
SCALE:15X

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NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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