

# LMP8645, LMP8645HV Precision High Voltage Current Sense Amplifier

## 1 Features

- Typical Values,  $T_A = 25^\circ\text{C}$
- High Common-Mode Voltage Range
  - LMP8645  $-2\text{ V}$  to  $42\text{ V}$
  - LMP8645HV  $-2\text{ V}$  to  $76\text{ V}$
- Supply Voltage Range  $2.7\text{ V}$  to  $12\text{ V}$
- Gain Configurable With a Single Resistor
- Maximum Variable Gain Accuracy (With External Resistor) 2%
- Transconductance  $200\text{ }\mu\text{A/V}$
- Low Offset Voltage  $1\text{ mV}$
- Input Bias  $12\text{ }\mu\text{A}$
- PSRR 90 dB
- CMRR 95 dB
- Temperature Range  $-40^\circ\text{C}$  to  $125^\circ\text{C}$
- 6-Pin SOT Package

## 2 Applications

- High-Side Current Sense
- Vehicle Current Measurement
- Motor Controls
- Battery Monitoring
- Remote Sensing
- Power Management

## 3 Description

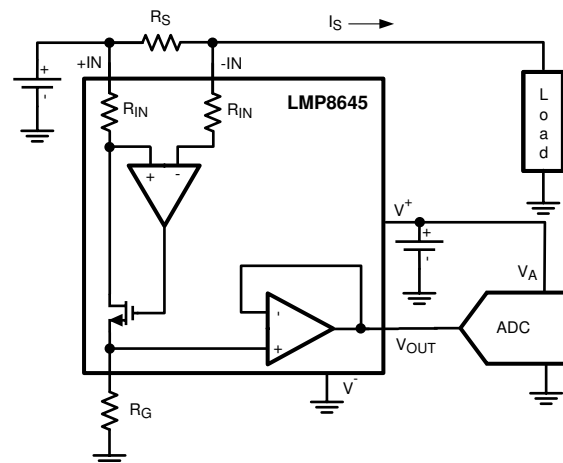
The LMP8645 and the LMP8645HV devices are precision current sense amplifiers that detect small differential voltages across a sense resistor in the presence of high-input common-mode voltages.

Operating from a supply range of  $2.7\text{ V}$  to  $12\text{ V}$ , the LMP8645 accepts input signals with a common-mode voltage range of  $-2\text{ V}$  to  $42\text{ V}$ , while the LMP8645HV accepts input signals with a common-mode voltage range of  $-2\text{ V}$  to  $76\text{ V}$ . The LMP8645 and LMP8645HV have adjustable gain for applications where supply current and high common-mode voltage are the determining factors. The gain is configured with a single resistor, providing a high level of flexibility, as well as accuracy as low as 2% (maximum) including the gain setting resistor. The output is buffered to provide low output impedance. This high-side current sense amplifier is ideal for sensing and monitoring currents in DC or battery-powered systems, has excellent AC and DC specifications over temperature, and keeps errors in the current sense loop to a minimum. The LMP8645 is an ideal choice for industrial, automotive, and consumer applications, and is available in SOT-6 package.

### Device Information<sup>(1)</sup>

| PART NUMBER | PACKAGE | BODY SIZE (NOM)   |
|-------------|---------|-------------------|
| LMP8645     | SOT (6) | 1.60 mm × 2.90 mm |
| LMP8645HV   |         |                   |

(1) For all available packages, see the orderable addendum at the end of the data sheet.



### Typical Application



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## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

|                                                                                                                                                                                                                                                                                                                                                     |             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>Changes from Revision G (September 2015) to Revision H (May 2022)</b> .....                                                                                                                                                                                                                                                                      | <b>Page</b> |
| • Updated the numbering format for tables, figures, and cross-references throughout the document.....                                                                                                                                                                                                                                               | <b>1</b>    |
| • Removed <i>Absolute Maximum Ratings</i> tablenote: If Military/Aerospace specified devices are required, contact the Texas Instruments Sales Office/Distributors for availability and specifications.....                                                                                                                                         | <b>3</b>    |
| <b>Changes from Revision F (March 2013) to Revision G (September 2015)</b> .....                                                                                                                                                                                                                                                                    | <b>Page</b> |
| • Added <i>ESD Ratings</i> table, <i>Feature Description</i> section, <i>Device Functional Modes</i> , <i>Application and Implementation</i> section, <i>Power Supply Recommendations</i> section, <i>Layout</i> section, <i>Device and Documentation Support</i> section, and <i>Mechanical, Packaging, and Orderable Information</i> section..... | <b>1</b>    |
| <b>Changes from Revision E (March 2013) to Revision F (March 2013)</b> .....                                                                                                                                                                                                                                                                        | <b>Page</b> |
| • Changed layout of National Data Sheet to TI format.....                                                                                                                                                                                                                                                                                           | <b>19</b>   |

## 5 Pin Configuration and Functions

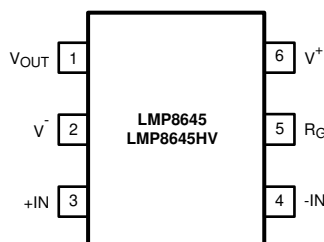


Figure 5-1. DD Package 6-Pin SOT Top View

Table 5-1. Pin Functions

| PIN              |     | I/O | DESCRIPTION             |
|------------------|-----|-----|-------------------------|
| NAME             | NO. |     |                         |
| V <sub>OUT</sub> | 1   | O   | Single-ended output     |
| V <sup>-</sup>   | 2   | P   | Negative supply voltage |
| +IN              | 3   | I   | Positive input          |
| -IN              | 4   | I   | Negative input          |
| R <sub>G</sub>   | 5   | I/O | External gain resistor  |
| V <sup>+</sup>   | 6   | P   | Positive supply voltage |

## 6 Specifications

### 6.1 Absolute Maximum Ratings

See (1) (2) (3)

|                                       |           | MIN            | MAX            | UNIT |
|---------------------------------------|-----------|----------------|----------------|------|
| Supply Voltage ( $V_S = V^+ - V^-$ )  |           |                | 13.2           | V    |
| Differential voltage +IN- (-IN)       |           |                | 6              | V    |
| Voltage at pins +IN, -IN              | LMP8645HV | -6             | 80             | V    |
|                                       | LMP8645   | -6             | 60             | V    |
| Voltage at R <sub>G</sub> pin         |           |                | 13.2           | V    |
| Voltage at OUT pin                    |           | V <sup>-</sup> | V <sup>+</sup> | V    |
| Junction temperature <sup>(2)</sup>   |           |                | 150            | °C   |
| Storage temperature, T <sub>stg</sub> |           | -65            | 150            | °C   |

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) The maximum power dissipation must be derated at elevated temperatures and is dictated by T<sub>J(MAX)</sub>, R<sub>θJA</sub>, and the ambient temperature, T<sub>A</sub>. The maximum allowable power dissipation P<sub>DMAX</sub> = (T<sub>J(MAX)</sub> - T<sub>A</sub>) / R<sub>θJA</sub> or the number given in Absolute Maximum Ratings, whichever is lower.
- (3) For soldering specifications, refer to [SNOA549](#)

### 6.2 ESD Ratings

|                                            |                                                                                |                         | VALUE | UNIT |
|--------------------------------------------|--------------------------------------------------------------------------------|-------------------------|-------|------|
| V <sub>(ESD)</sub> Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/ JEDEC JS-001 <sup>(1) (3)</sup>         | All pins except 3 and 4 | ±2000 | V    |
|                                            |                                                                                | Pins 3 and 4            | ±5000 |      |
|                                            | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> |                         | ±1250 |      |
|                                            | Machine Model                                                                  |                         | ±200  |      |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

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- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.
- (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).

### 6.3 Recommended Operating Conditions

|                                      | MIN | MAX | UNIT |
|--------------------------------------|-----|-----|------|
| Supply voltage ( $V_S = V^+ - V^-$ ) | 2.7 | 12  | V    |
| Temperature range <sup>(1)</sup>     | -40 | 125 | °C   |

- (1) The maximum power dissipation must be derated at elevated temperatures and is dictated by  $T_{J(MAX)}$ ,  $R_{\theta JA}$ , and the ambient temperature,  $T_A$ . The maximum allowable power dissipation  $P_{DMAX} = (T_{J(MAX)} - T_A) / R_{\theta JA}$  or the number given in Absolute Maximum Ratings, whichever is lower.

### 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup>                                         | LMV8645,<br>LMV8645HV | UNIT |
|-----------------------------------------------------------------------|-----------------------|------|
|                                                                       | DDC (SOT)             |      |
|                                                                       | 6 PINS                |      |
| $R_{\theta JA}$ Junction-to-ambient thermal resistance <sup>(2)</sup> | 96                    | °C/W |

- (1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, [SPRA953](#).
- (2) The maximum power dissipation must be derated at elevated temperatures and is dictated by  $T_{J(MAX)}$ ,  $R_{\theta JA}$ , and the ambient temperature,  $T_A$ . The maximum allowable power dissipation  $P_{DMAX} = (T_{J(MAX)} - T_A) / R_{\theta JA}$  or the number given in Absolute Maximum Ratings, whichever is lower.

## 6.5 2.7-V Electrical Characteristics

Unless otherwise specified, all limits specified for at  $T_A = 25^\circ\text{C}$ ,  $V_S = V^+ - V^-$ ,  $V^+ = 2.7\text{ V}$ ,  $V^- = 0\text{ V}$ ,  $-2\text{ V} < V_{CM} < 76\text{ V}$ ,  $R_G = 25\text{ k}\Omega$ ,  $R_L = 10\text{ M}\Omega$ .<sup>(1)</sup>

| PARAMETER       |                                                  | TEST CONDITIONS                                                                                                                                    | MIN <sup>(3)</sup> | TYP <sup>(2)</sup> | MAX <sup>(3)</sup> | UNIT                         |
|-----------------|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| $V_{OS}$        | Input Offset Voltage                             | $V_{CM} = 2.1\text{ V}$                                                                                                                            | -1                 |                    | 1                  | mV                           |
|                 |                                                  | At the temperature extremes                                                                                                                        | -1.7               |                    | 1.7                |                              |
| $TCV_{OS}$      | Input Offset Voltage Drift <sup>(4)</sup><br>(6) | $V_{CM} = 2.1\text{ V}$                                                                                                                            |                    |                    | 7                  | $\mu\text{V}/^\circ\text{C}$ |
| $I_B$           | Input Bias Current <sup>(7)</sup>                | $V_{CM} = 2.1\text{ V}$                                                                                                                            |                    | 12                 | 20                 | $\mu\text{A}$                |
| $e_{ni}$        | Input Voltage Noise <sup>(6)</sup>               | $f > 10\text{ kHz}$ , $R_G = 5\text{ k}\Omega$                                                                                                     |                    | 120                |                    | $\text{nV}/\sqrt{\text{Hz}}$ |
| $V_{SENSE(MA)}$ | Max Input Sense Voltage <sup>(6)</sup>           | $V_{CM} = 12\text{ V}$ , $R_G = 5\text{ k}\Omega$                                                                                                  |                    | 600                |                    | mV                           |
| Gain $A_V$      | Adjustable Gain Setting <sup>(6)</sup>           | $V_{CM} = 12\text{ V}$                                                                                                                             | 1                  |                    | 100                | V/V                          |
| $G_m$           | Transconductance                                 | $V_{CM} = 2.1\text{ V}$                                                                                                                            |                    | 200                |                    | $\mu\text{A}/\text{V}$       |
|                 | Accuracy                                         | $V_{CM} = 2.1\text{ V}$                                                                                                                            | -2%                |                    | 2%                 |                              |
|                 |                                                  | At the temperature extremes                                                                                                                        | -3.4%              |                    | 3.4%               |                              |
|                 | Gm drift <sup>(6)</sup>                          | $-40^\circ\text{C}$ to $125^\circ\text{C}$ , $V_{CM} = 2.1\text{ V}$                                                                               |                    |                    | 140                | $\text{ppm}/^\circ\text{C}$  |
| PSRR            | Power Supply Rejection Ratio                     | $V_{CM} = 2.1\text{ V}$ , $2.7\text{ V} < V^+ < 12\text{ V}$                                                                                       | 90                 |                    |                    | dB                           |
| CMRR            | Common-Mode Rejection Ratio                      | LMP8645HV $2.1\text{ V} < V_{CM} < 76\text{ V}$<br>LMP8645 $2.1\text{ V} < V_{CM} < 42\text{ V}$                                                   | 95                 |                    |                    | dB                           |
|                 |                                                  | $-2\text{ V} < V_{CM} < 2\text{ V}$                                                                                                                | 60                 |                    |                    |                              |
| BW              | -3-dB Bandwidth <sup>(6)</sup>                   | $R_G = 10\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 400\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                 |                    | 990                |                    | kHz                          |
|                 |                                                  | $R_G = 25\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 200\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                 |                    | 260                |                    |                              |
|                 |                                                  | $R_G = 50\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 100\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                 |                    | 135                |                    |                              |
| SR              | Slew Rate <sup>(5)</sup> (6)                     | $V_{CM} = 5\text{ V}$ , $C_G = 4\text{ pF}$ , $V_{SENSE}$ from $25\text{ mV}$ to $175\text{ mV}$ , $C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$ |                    | 0.5                |                    | $\text{V}/\mu\text{s}$       |
| $I_S$           | Supply Current                                   | $V_{CM} = 2.1\text{ V}$                                                                                                                            |                    | 380                | 525                | $\mu\text{A}$                |
|                 |                                                  | At the temperature extremes                                                                                                                        |                    |                    | 710                |                              |
|                 |                                                  | $V_{CM} = -2\text{ V}$                                                                                                                             |                    | 2000               | 2500               |                              |
|                 |                                                  | At the temperature extremes                                                                                                                        |                    |                    | 2700               |                              |
| $V_{OUT}$       | Maximum Output Voltage                           | $V_{CM} = 2.1\text{ V}$ , $R_G = 500\text{ k}\Omega$                                                                                               | 1.2                |                    |                    | V                            |
|                 | Minimum Output Voltage                           | $V_{CM} = 2.1\text{ V}$                                                                                                                            |                    |                    | 20                 | mV                           |
| $I_{OUT}$       | Output current <sup>(6)</sup>                    | Sourcing, $V_{OUT} = 600\text{ mV}$ , $R_G = 150\text{ k}\Omega$                                                                                   |                    | 5                  |                    | mA                           |
|                 |                                                  | Sinking, $V_{OUT} = 600\text{ mV}$ , $R_G = 150\text{ k}\Omega$                                                                                    |                    | 5                  |                    |                              |
| $C_{LOAD}$      | Max Output Capacitance Load <sup>(6)</sup>       |                                                                                                                                                    |                    | 30                 |                    | pF                           |

- (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 specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ .
- (2) 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) All limits are specified by testing, design, or statistical analysis.
- (4) Offset voltage temperature drift is determined by dividing the change in  $V_{OS}$  at the temperature extremes by the total temperature change.
- (5) The number specified is the average of rising and falling slew rates and measured at 90% to 10%.
- (6) This parameter is specified by design and/or characterization and is not tested in production.
- (7) Positive Bias Current corresponds to current flowing into the device.

## 6.6 5-V Electrical Characteristics

Unless otherwise specified, all limits specified for at  $T_A = 25^\circ\text{C}$ ,  $V_S = V^+ - V^-$ ,  $V^+ = 5\text{ V}$ ,  $V^- = 0\text{ V}$ ,  $-2\text{ V} < V_{CM} < 76\text{ V}$ ,  $R_g = 25\text{ k}\Omega$ ,  $R_L = 10\text{ M}\Omega$ .<sup>(1)</sup>

| PARAMETER         |                                                  | TEST CONDITIONS                                                                                                                                     | MIN <sup>(3)</sup> | TYP <sup>(2)</sup> | MAX <sup>(3)</sup> | UNIT                         |
|-------------------|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| $V_{OS}$          | Input Offset Voltage                             | $V_{CM} = 2.1\text{ V}$<br>At the temperature extremes                                                                                              | -1                 |                    | 1                  | mV                           |
|                   |                                                  |                                                                                                                                                     | -1.7               |                    | 1.7                |                              |
| $TCV_{OS}$        | Input Offset Voltage Drift <sup>(4)</sup><br>(6) | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    |                    | 7                  | $\mu\text{V}/^\circ\text{C}$ |
| $I_B$             | Input Bias Current <sup>(7)</sup>                | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    | 12.5               | 22                 | $\mu\text{A}$                |
| $e_{ni}$          | Input Voltage Noise <sup>(6)</sup>               | $f > 10\text{ kHz}$ , $R_G = 5\text{ k}\Omega$                                                                                                      |                    | 120                |                    | $\text{nV}/\sqrt{\text{Hz}}$ |
| $V_{SENSE(MA X)}$ | Max Input Sense Voltage <sup>(6)</sup>           | $V_{CM} = 12\text{ V}$ , $R_G = 5\text{ k}\Omega$                                                                                                   |                    | 600                |                    | mV                           |
| Gain $A_V$        | Adjustable Gain Setting <sup>(6)</sup>           | $V_{CM} = 12\text{ V}$                                                                                                                              | 1                  |                    | 100                | V/V                          |
| $G_m$             | Transconductance                                 | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    | 200                |                    | $\mu\text{A}/\text{V}$       |
|                   | Accuracy                                         | $V_{CM} = 2.1\text{ V}$<br>At the temperature extremes                                                                                              | -2%                |                    | 2%                 |                              |
|                   |                                                  |                                                                                                                                                     | -3.4%              |                    | 3.4%               |                              |
|                   | Gm drift <sup>(6)</sup>                          | $-40^\circ\text{C}$ to $125^\circ\text{C}$ , $V_{CM} = 2.1\text{ V}$                                                                                |                    |                    | 140                | $\text{ppm}/^\circ\text{C}$  |
| PSRR              | Power Supply Rejection Ratio                     | $V_{CM} = 2.1\text{ V}$ , $2.7\text{ V} < V^+ < 12\text{ V}$                                                                                        | 90                 |                    |                    | dB                           |
| CMRR              | Common-Mode Rejection Ratio                      | LMP8645HV $2.1\text{ V} < V_{CM} < 76\text{ V}$<br>LMP8645 $2.1\text{ V} < V_{CM} < 42\text{ V}$                                                    | 95                 |                    |                    | dB                           |
|                   |                                                  | $-2\text{ V} < V_{CM} < 2\text{ V}$                                                                                                                 | 60                 |                    |                    |                              |
| BW                | -3-dB Bandwidth <sup>(6)</sup>                   | $R_G = 10\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 400\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                  |                    | 850                |                    | kHz                          |
|                   |                                                  | $R_G = 25\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 300\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                  |                    | 260                |                    |                              |
|                   |                                                  | $R_G = 50\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 300\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                  |                    | 140                |                    |                              |
| SR                | Slew Rate <sup>(5)</sup> (6)                     | $V_{CM} = 5\text{ V}$ , $C_G = 4\text{ pF}$ , $V_{SENSE}$ from $100\text{ mV}$ to $500\text{ mV}$ , $C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$ |                    | 0.5                |                    | $\text{V}/\mu\text{s}$       |
| $I_S$             | Supply Current                                   | $V_{CM} = 2.1\text{ V}$<br>At the temperature extremes                                                                                              |                    | 450                | 610                | $\mu\text{A}$                |
|                   |                                                  |                                                                                                                                                     |                    |                    | 780                |                              |
|                   |                                                  | $V_{CM} = -2\text{ V}$<br>At the temperature extremes                                                                                               |                    | 2100               | 2800               |                              |
|                   |                                                  |                                                                                                                                                     |                    |                    | 3030               |                              |
| $V_{OUT}$         | Maximum Output Voltage                           | $V_{CM} = 5\text{ V}$ , $R_g = 500\text{ k}\Omega$                                                                                                  | 3.3                |                    |                    | V                            |
|                   | Minimum Output Voltage                           | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    |                    | 22                 | mV                           |
| $I_{OUT}$         | Output current <sup>(6)</sup>                    | Sourcing, $V_{OUT} = 1.65\text{ V}$ , $R_g = 150\text{ k}\Omega$                                                                                    |                    | 5                  |                    | mA                           |
|                   |                                                  | Sinking, $V_{OUT} = 1.65\text{ V}$ , $R_g = 150\text{ k}\Omega$                                                                                     |                    | 5                  |                    |                              |
| $C_{LOAD}$        | Max Output Capacitance Load <sup>(6)</sup>       |                                                                                                                                                     |                    | 30                 |                    | pF                           |

- (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 specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ .
- (2) 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) All limits are specified by testing, design, or statistical analysis.
- (4) Offset voltage temperature drift is determined by dividing the change in  $V_{OS}$  at the temperature extremes by the total temperature change.
- (5) The number specified is the average of rising and falling slew rates and measured at 90% to 10%.
- (6) This parameter is specified by design and/or characterization and is not tested in production.
- (7) Positive Bias Current corresponds to current flowing into the device.

## 6.7 12-V Electrical Characteristics

Unless otherwise specified, all limits specified for at  $T_A = 25^\circ\text{C}$ ,  $V_S = V^+ - V^-$ ,  $V^+ = 12\text{ V}$ ,  $V^- = 0\text{ V}$ ,  $-2\text{ V} < V_{CM} < 76\text{ V}$ ,  $R_G = 25\text{ k}\Omega$ ,  $R_L = 10\text{ M}\Omega$ .<sup>(1)</sup>

| PARAMETER       |                                                  | TEST CONDITIONS                                                                                                                                     | MIN <sup>(3)</sup> | TYP <sup>(2)</sup> | MAX <sup>(3)</sup> | UNIT                         |
|-----------------|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|--------------------|--------------------|------------------------------|
| $V_{OS}$        | Input Offset Voltage                             | $V_{CM} = 2.1\text{ V}$<br>At the temperature extremes                                                                                              | -1                 |                    | 1                  | mV                           |
|                 |                                                  |                                                                                                                                                     | -1.7               |                    | 1.7                |                              |
| $TCV_{OS}$      | Input Offset Voltage Drift <sup>(4)</sup><br>(6) | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    |                    | 7                  | $\mu\text{V}/^\circ\text{C}$ |
| $I_B$           | Input Bias Current <sup>(7)</sup>                | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    | 13                 | 23                 | $\mu\text{A}$                |
| $e_{ni}$        | Input Voltage Noise <sup>(6)</sup>               | $f > 10\text{ kHz}$ , $R_G = 5\text{ k}\Omega$                                                                                                      |                    | 120                |                    | $\text{nV}/\sqrt{\text{Hz}}$ |
| $V_{SENSE(MA)}$ | Max Input Sense Voltage <sup>(6)</sup>           | $V_{CM} = 12\text{ V}$ , $R_G = 5\text{ k}\Omega$                                                                                                   |                    | 600                |                    | mV                           |
| Gain $A_V$      | Adjustable Gain Setting <sup>(6)</sup>           | $V_{CM} = 12\text{ V}$                                                                                                                              | 1                  |                    | 100                | V/V                          |
| $G_m$           | Transconductance                                 | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    | 200                |                    | $\mu\text{A}/\text{V}$       |
|                 | Accuracy                                         | $V_{CM} = 2.1\text{ V}$<br>At the temperature extremes                                                                                              | -2%                |                    | 2%                 |                              |
|                 |                                                  |                                                                                                                                                     | -3.4%              |                    | 3.4%               |                              |
|                 | Gm drift <sup>(6)</sup>                          | $-40^\circ\text{C}$ to $125^\circ\text{C}$ , $V_{CM} = 2.1\text{ V}$                                                                                |                    |                    | 140                | $\text{ppm}/^\circ\text{C}$  |
| PSRR            | Power Supply Rejection Ratio                     | $V_{CM} = 2.1\text{ V}$ , $2.7\text{ V} < V^+ < 12\text{ V}$                                                                                        | 90                 |                    |                    | dB                           |
| CMRR            | Common-Mode Rejection Ratio                      | LMP8645HV $2.1\text{ V} < V_{CM} < 76\text{ V}$<br>LMP8645 $2.1\text{ V} < V_{CM} < 42\text{ V}$                                                    | 95                 |                    |                    | dB                           |
|                 |                                                  | $-2\text{ V} < V_{CM} < 2\text{ V}$                                                                                                                 | 60                 |                    |                    |                              |
| BW              | -3-dB Bandwidth <sup>(6)</sup>                   | $R_G = 10\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 400\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                  |                    | 860                |                    | kHz                          |
|                 |                                                  | $R_G = 25\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 400\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                  |                    | 260                |                    |                              |
|                 |                                                  | $R_G = 50\text{ k}\Omega$ , $C_G = 4\text{ pF}$ , $V_{SENSE} = 400\text{ mV}$ ,<br>$C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$                  |                    | 140                |                    |                              |
| SR              | Slew Rate <sup>(5)</sup> (6)                     | $V_{CM} = 5\text{ V}$ , $C_G = 4\text{ pF}$ , $V_{SENSE}$ from $100\text{ mV}$ to $500\text{ mV}$ , $C_L = 30\text{ pF}$ , $R_L = 1\text{ M}\Omega$ |                    | 0.6                |                    | $\text{V}/\mu\text{s}$       |
| $I_S$           | Supply Current                                   | $V_{CM} = 2.1\text{ V}$<br>At the temperature extremes                                                                                              |                    | 555                | 765                | $\mu\text{A}$                |
|                 |                                                  |                                                                                                                                                     |                    |                    | 920                |                              |
|                 |                                                  | $V_{CM} = -2\text{ V}$<br>At the temperature extremes                                                                                               |                    | 2200               | 2900               |                              |
|                 |                                                  |                                                                                                                                                     |                    |                    | 3110               |                              |
| $V_{OUT}$       | Maximum Output Voltage                           | $V_{CM} = 12\text{ V}$ , $R_G = 500\text{ k}\Omega$                                                                                                 | 10.2               |                    |                    | V                            |
|                 | Minimum Output Voltage                           | $V_{CM} = 2.1\text{ V}$                                                                                                                             |                    |                    | 24                 | mV                           |
| $I_{OUT}$       | Output current <sup>(6)</sup>                    | Sourcing, $V_{OUT} = 5.25\text{ V}$ , $R_G = 150\text{ k}\Omega$                                                                                    |                    | 5                  |                    | mA                           |
|                 |                                                  | Sinking, $V_{OUT} = 5.25\text{ V}$ , $R_G = 150\text{ k}\Omega$                                                                                     |                    | 5                  |                    |                              |
| $C_{LOAD}$      | Max Output Capacitance Load <sup>(6)</sup>       |                                                                                                                                                     |                    | 30                 |                    | pF                           |

- (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 specification of parametric performance is indicated in the electrical tables under conditions of internal self-heating where  $T_J > T_A$ .
- (2) 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) All limits are specified by testing, design, or statistical analysis.
- (4) Offset voltage temperature drift is determined by dividing the change in  $V_{OS}$  at the temperature extremes by the total temperature change.
- (5) The number specified is the average of rising and falling slew rates and measured at 90% to 10%.
- (6) This parameter is specified by design and/or characterization and is not tested in production.
- (7) Positive Bias Current corresponds to current flowing into the device.

## 6.8 Typical Characteristics

Unless otherwise specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = V^+ - V^-$ ,  $V_{\text{SENSE}} = +\text{IN} - (-\text{IN})$ ,  $R_L = 10\text{ M}\Omega$ .

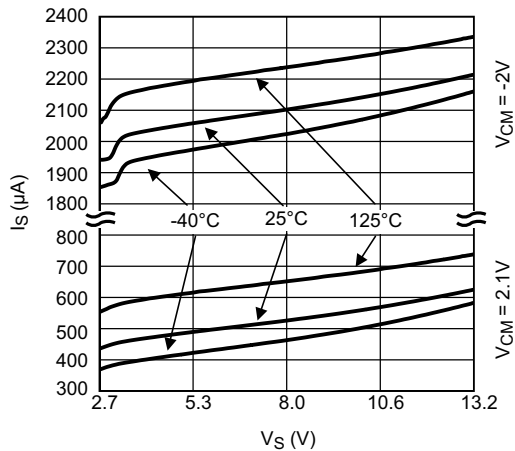


Figure 6-1. Supply Current vs. Supply Voltage

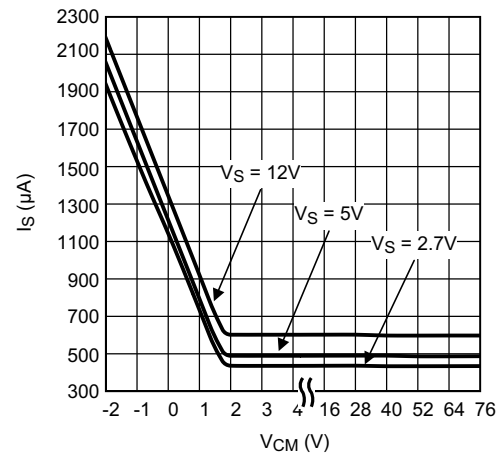


Figure 6-2. Supply Current vs.  $V_{\text{CM}}$

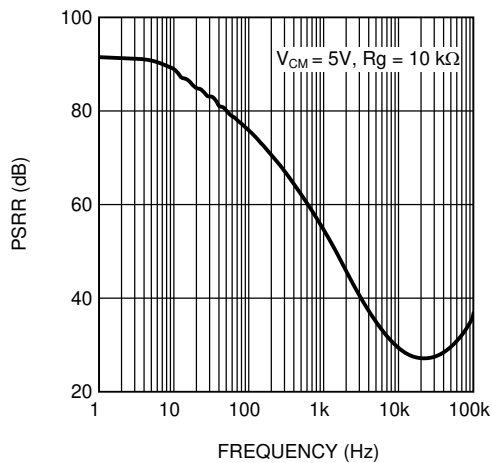


Figure 6-3. AC PSRR vs. Frequency

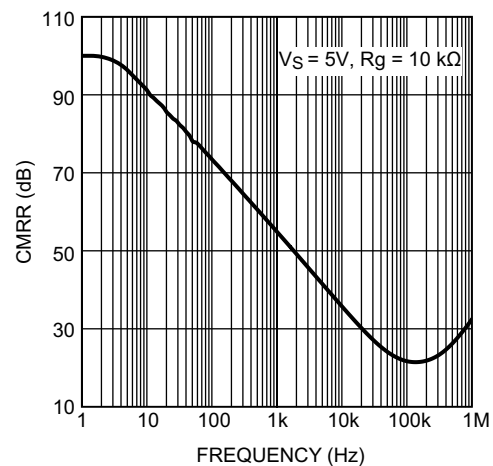


Figure 6-4. AC CMRR vs. Frequency

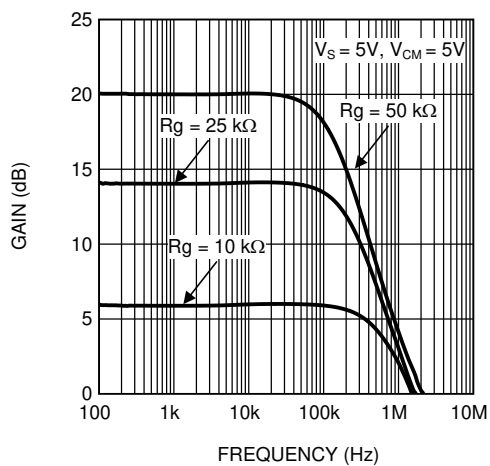


Figure 6-5. Gain vs. Frequency

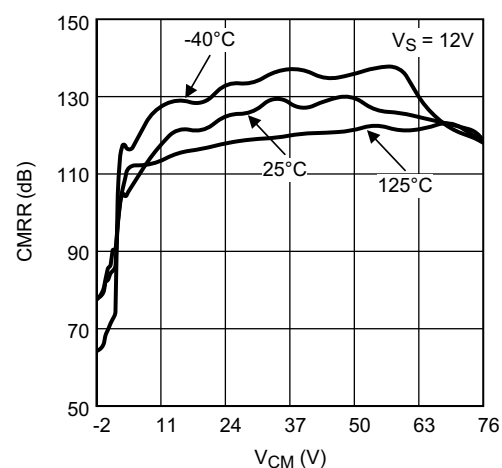


Figure 6-6. CMRR vs.  $V_{\text{CM}}$

## 6.8 Typical Characteristics (continued)

Unless otherwise specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = V^+ - V^-$ ,  $V_{\text{SENSE}} = +\text{IN} - (-\text{IN})$ ,  $R_L = 10\text{ M}\Omega$ .

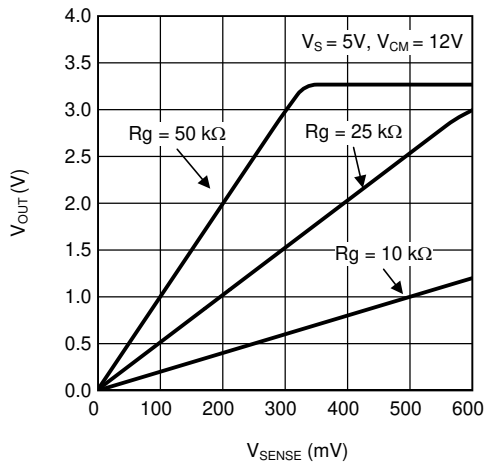


Figure 6-7. Output Voltage vs.  $V_{\text{SENSE}}$

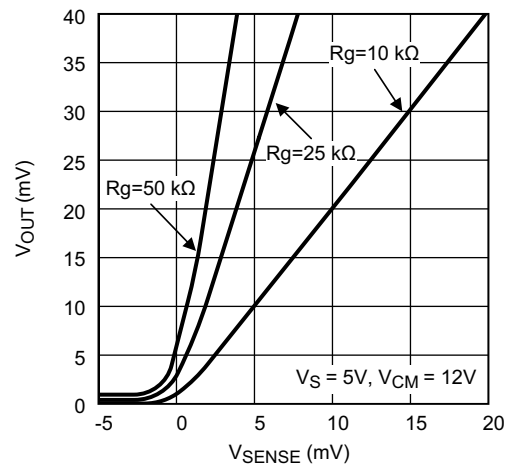


Figure 6-8. Output Voltage vs.  $V_{\text{SENSE}}$  (ZOOM Close to 0 V)

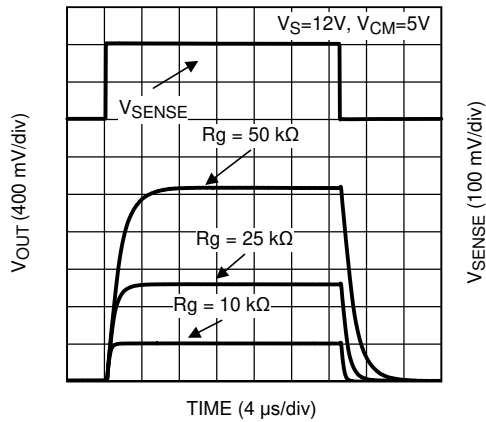


Figure 6-9. Large Step Response

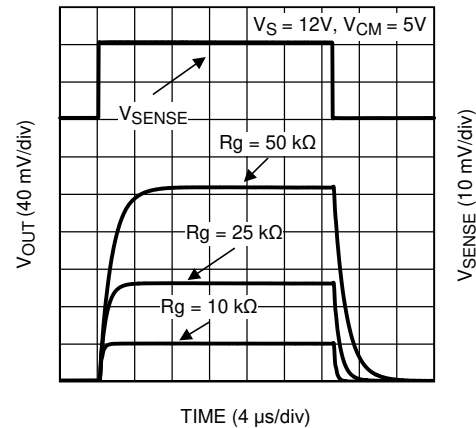


Figure 6-10. Small Step Response

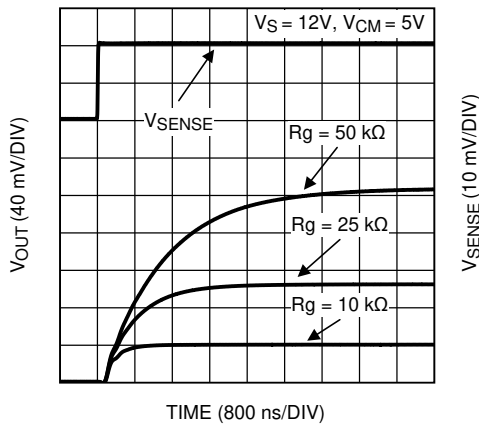


Figure 6-11. Settling Time (Rise)

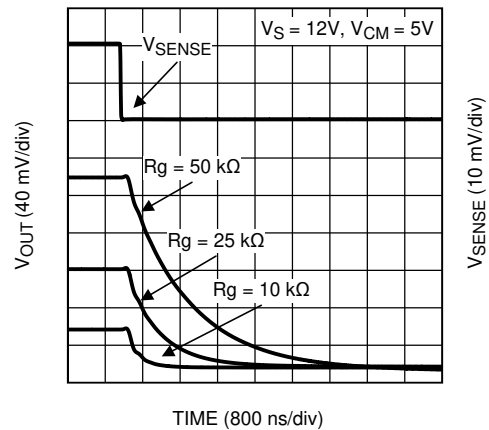


Figure 6-12. Settling Time (Fall)

## 6.8 Typical Characteristics (continued)

Unless otherwise specified:  $T_A = 25^\circ\text{C}$ ,  $V_S = V^+ - V^-$ ,  $V_{\text{SENSE}} = +\text{IN} - (-\text{IN})$ ,  $R_L = 10\text{ M}\Omega$ .

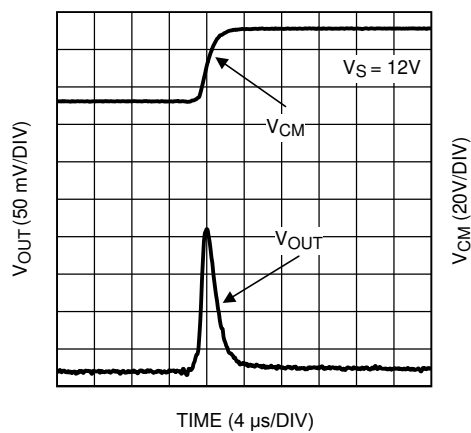


Figure 6-13. Common-Mode Step Response (Rise)

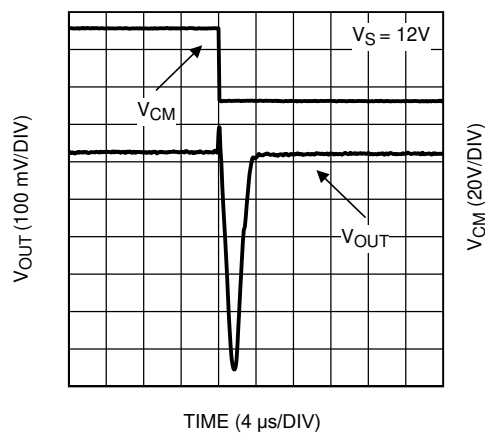


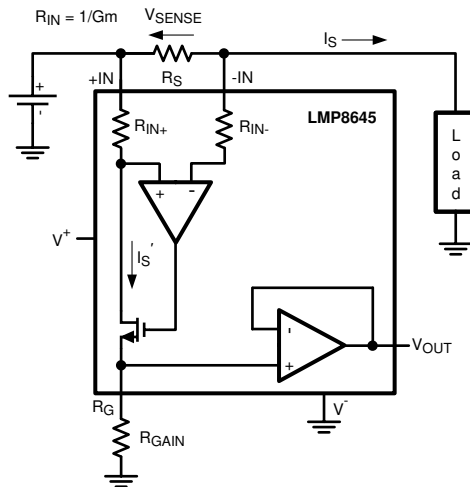
Figure 6-14. Common-Mode Step Response (Fall)

## 7 Detailed Description

### 7.1 Overview

Operating from a 2.7-V to 12-V supply range, the LMP8645 accepts input signals with a common-mode voltage range of –2 V to 42 V, while the LMP8645HV accepts input signals with a common-mode voltage range of –2 V to 76 V. The LMP8645 and LMP8645HV have adjustable gain, set by a single resistor, for applications where supply current and high common-mode voltage are the determining factors.

#### 7.1.1 Theory of Operation



**Figure 7-1. Current Monitor Example Circuit**

As seen in Figure 7-1, the current flowing through the shunt resistor ( $R_S$ ) develops a voltage drop equal to  $V_{SENSE}$  across  $R_S$ . The resulting voltage at the –IN pin will now be less than +IN pin proportional to the  $V_{SENSE}$  voltage.

The sense amplifier senses this difference and increases the gate drive to the MOSFET to increase  $I_S'$  current flowing through the  $R_{IN+}$  string until the amplifier inputs are equal. In this way, the voltage drop across  $R_{IN+}$  now matches the voltage drop across  $V_{SENSE}$ .

The  $R_{IN}$  resistors are trimmed to a nominal value of 5 k $\Omega$  each. The current  $I_S'$  flows through  $R_{IN+}$ , the MOSFET, and  $R_{GAIN}$  to ground. The  $I_S'$  current generates the voltage  $V_G$  across  $R_{GAIN}$ . The gain is created by the ratio of  $R_{GAIN}$  and  $R_{IN}$ .

A current proportional to  $I_S$  is generated according to the following relation:

$$I_S' = V_{SENSE} / R_{IN} = R_S \times I_S / R_{IN} \quad (1)$$

where

- $R_{IN} = 1 / G_m$

This current flows entirely in the external gain resistor developing a voltage drop equal to:

$$V_G = I_S' \times R_{GAIN} = (V_{SENSE} / R_{IN}) \times R_{GAIN} = (R_S \times I_S) / R_{IN} \times R_{GAIN} \quad (2)$$

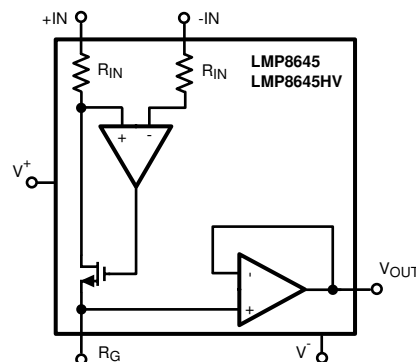
This voltage is buffered and presented at the output with a very low output impedance allowing a very easy interface to other devices (ADC,  $\mu C$ ...).

$$V_{OUT} = (R_S \times I_S) \times G \quad (3)$$

where

- $G = R_{GAIN} / R_{IN}$

## 7.2 Functional Block Diagram



## 7.3 Feature Description

### 7.3.1 Driving ADC

The input stage of an Analog-to-Digital converter can be modeled with a resistor and a capacitance versus ground. So if the voltage source does not have a low impedance, an error in the measurement of the amplitude will occur. In this condition a buffer is needed to drive the ADC. The LMP8645 has an internal output buffer able to drive a capacitance load up to 30 pF or the input stage of an ADC. If required an external lowpass RC filter can be added at the output of the LMP8645 to reduce the noise and the bandwidth of the current sense. Any other filter solution that implies a capacitance connected to the  $R_G$  pin is not suggested due to the high impedance of that pin.

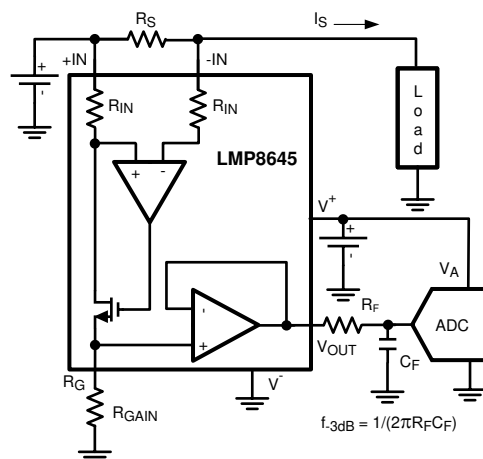


Figure 7-2. LMP8645 to ADC Interface

### 7.3.2 Applying Input Voltage With No Supply Voltage

The full specified input common-mode voltage range may be applied to the inputs while the LMP8645 power is off ( $V_+ = 0$  V). When the LMP8640 is powered off, the  $R_{IN}$  resistors are disconnected internally by MOSFETS and the leakage currents are very low (sub  $\mu$ A).

The 6-V input differential limit still applies, so at no time should the two inputs be more than 6-V apart. There are also Zener clamps on the inputs to ground, so do not exceed the input limits specified in the [Absolute Maximum Ratings](#).

## 7.4 Device Functional Modes

### 7.4.1 Selection of the Gain Resistor

For the LMP8645 and LMP8645HV, the gain is selected through an external gain set resistor connected to the  $R_G$  pin. Moreover, the gain resistor  $R_{GAIN}$  determines the voltage of the output buffer, which is related to the supply voltage and also to the common-mode voltage of the input signal.

### 7.4.2 Gain Range Limitations

The gain resistor must be chosen such that the theoretical maximum output voltage does not exceed the LMP8645 maximum output voltage rating for a given common-mode voltage. These limits are due to the internal amplifier bias point and the  $V_{CM}$  headroom required to generate the required currents across the  $R_{IN}$  and  $R_{GAIN}$  resistors.

The following sections explain how to select the gain resistor for various ranges of the input common-mode voltage.

#### 7.4.2.1 Range 1: $V_{CM}$ is $-2\text{ V}$ to $1.8\text{ V}$

The maximum voltage at the  $R_G$  pin is given by the following inequality:

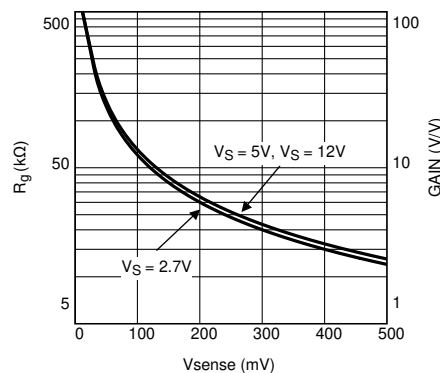
$$V_{RG} = V_{sense} \times R_{GAIN} \times G_m \leq \min(1.3\text{ V}; V_{out\_max}) \quad (4)$$

where

- $V_{out\_max}$  is the maximum allowable output voltage according to the Electrical Tables

All the gain resistors ( $R_{GAIN}$ ) values which respect the previous inequality are allowed. The graphical representation of Figure 7-3 helps in the selection.

All the combinations ( $V_{SENSE}$ ,  $R_{GAIN}$ ) below the curve are allowed.



**Figure 7-3. Allowed Gains for Range 1**

As a consequence, once selected, the gain ( $R_{GAIN}$ ) and the  $V_{SENSE}$  range is fixed, too.

For example if an application required a Gain of 10,  $R_G$  will be 50 kΩ and  $V_{SENSE}$  will be in the range 10 mV to 100 mV.

#### 7.4.2.2 Range 2: $V_{CM}$ is $1.8\text{ V}$ to $V_S$

In this range, the maximum voltage at the  $R_G$  pin is related to the common-mode voltage and  $V_{SENSE}$ . So all the  $R_{GAIN}$  resistor values which respect the following inequalities are allowed:

$$V_{RG} \leq \min(V_{out\_max}; (V_{CM} - V_{sense} - 250\text{ mV})) \quad (5)$$

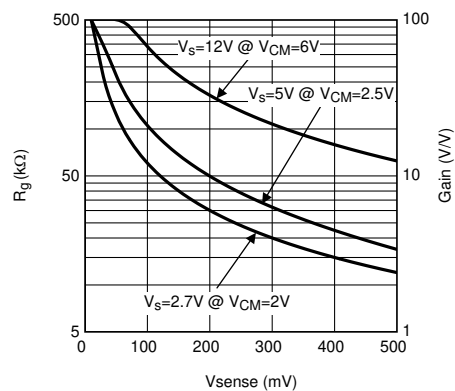
where

- $V_{RG} = V_{SENSE} \times R_{GAIN} \times G_m$

- $V_{out\_max}$  is the maximum allowable output voltage according to the [2.7-V Electrical Characteristics](#), [5-V Electrical Characteristics](#), and [12-V Electrical Characteristics](#).

The graphical representation in [Figure 7-4](#) helps in the selection.

All the combinations ( $V_{SENSE}$ ,  $R_{GAIN}$ ) below the curves for given  $V_{CM}$  and supply voltage are allowed.



**Figure 7-4. Allowed Gains for Range 2**

Also in this range, once selected, the  $R_{GAIN}$  (Gain) and the  $V_{SENSE}$  range is fixed too.

### 7.4.2.3 Range 3: $V_{CM}$ is greater than $V_S$

The maximum voltage at the  $R_G$  pin is  $V_{out\_max}$ , it means that:

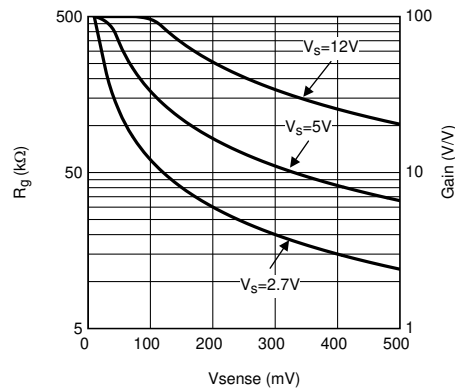
$$V_{OUT} = V_{SENSE} \times R_{GAIN} / R_{IN} \leq V_{out\_max} \quad (6)$$

where

- $V_{out\_max}$  is the maximum allowable output voltage according to the Electrical Tables

So all the  $R_{GAIN}$  resistors which respect the previous inequality are allowed. The graphical representation in [Figure 7-5](#) helps with the selection.

All the combinations ( $V_{SENSE}$ ,  $R_{GAIN}$ ) below the curves are allowed.



**Figure 7-5. Allowed Gains for Range 3**

Also in this range once selected the  $R_{GAIN}$  (Gain) the  $V_{SENSE}$  range is fixed too.

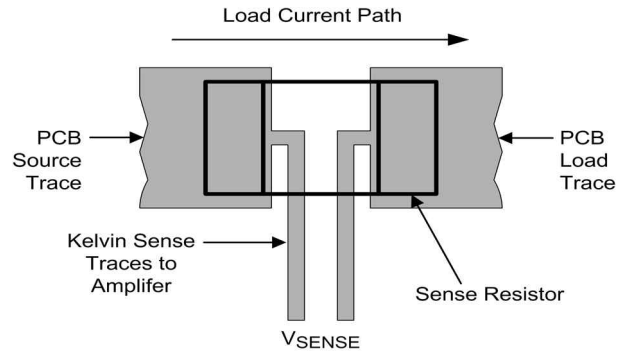
From the ranges shown above, a good way to maximize the output voltage swing of the LMP8645 is to select the maximum allowable  $R_{GAIN}$  according to the previous equations. For a fixed supply voltage and  $V_{SENSE}$  as the common-mode voltage increases, the maximum allowable  $R_{GAIN}$  increases too.

### 7.4.3 Selection of Sense Resistor

The accuracy of the current measurement highly depends on the value of the shunt resistor  $R_S$ . Its value depends on the application and it is a compromise between small-signal accuracy and maximum permissible voltage (and power) loss in the sense resistor. High values of  $R_S$  provide better accuracy at lower currents by minimizing the effects of amplifier offset. Low values of  $R_S$  minimize voltage and power loss in the supply section, but at the expense of low current accuracy. For most applications, best performance is obtained with an  $R_S$  value that provides a full-scale shunt voltage range of 100 mV to 200 mV.

In applications where a small current is sensed, a larger value of  $R_S$  is selected to minimize the error in the proportional output voltage. Higher resistor value improves the signal-to-noise ratio (SNR) at the input of the current sense amplifier and hence gives a more accurate output.

Similarly when high current is sensed, the power losses in  $R_S$  can be significant so a smaller value of  $R_S$  is desired. In this condition it is also required to take in account also the power rating of  $R_S$  resistor. The low input offset and customizable gain of the LMP8645 allows the use of small sense resistors to reduce power dissipation still providing a good input dynamic range. The input dynamic range is the ratio between the maximum signal that can be measured and the minimum signal that can be detected, where usually the input offset and amplifier noise are the principal limiting factors.



**Figure 7-6. Example of a Kelvin (4-Wire) Connection to a Two-Terminal Resistor**

The amplifier inputs should be directly connected to the sense resistor pads using *Kelvin* or *4-wire* connection techniques. The paths of the input traces should be identical, including connectors and vias, so that these errors will be equal and cancel.

#### 7.4.3.1 Resistor Power Rating and Thermal Issues

The power dissipated by the sense resistor can be calculated from:

$$P_D = I_{MAX}^2 * R_S \quad (7)$$

where

- $P_D$  is the power dissipated by the resistor in Watts
- $I_{MAX}$  is the maximum load current in A
- $R_S$  is the sense resistor value in  $\Omega$ .

The resistor must be rated for more than the expected maximum power ( $P_D$ ), with margin for temperature derating. Be sure to observe any power derating curves provided by the resistor manufacturer.

Running the resistor at higher temperatures will also affect the accuracy. As the resistor heats up, the resistance generally goes up, which will cause a change in the measurement. The sense resistor should have as much heat-sinking as possible to remove this heat through the use of heatsinks or large copper areas coupled to the resistor pads. A reading drifting slightly after turnon can usually be traced back to sense resistor heating.

#### 7.4.3.2 Using PCB Trace as a Sense Resistor

While it may be tempting to use the resistance of a known area of PCB trace or copper area as a sense resistor, TI does not recommend this for precision measurements.

The tempco of copper is typically 3300 to 4000 ppm/°K (0.33% to 0.4% per °C), which can vary with PCB processes.

A typical surface mount sense resistor temperature coefficient (tempco) is in the 50 ppm to 500 ppm per °C range offering more measurement consistency and accuracy over the copper trace. Special low tempco resistors are available in a range from 0.1 ppm to 50 ppm, but at a much higher cost.

#### 7.4.4 Sense Line Inputs

The sense lines should be connected to a point on the resistor that is not shared with the main current path, as shown in Figure 7-6. For lowest drift, the amplifier must be mounted away from any heat generating devices, which may include the sense resistor. The traces should be one continuous trace of copper from the sense resistor pad to the amplifier input pin pad, and ideally on the same copper layer with minimal vias or connectors. This can be important around the sense resistor if it is generating any significant heat gradients. Vias in the sense lines should be formed from continuous plated copper and routing through mating connectors or headers should be avoided. It is better to extend the sense lines than to place the amplifier in a hostile environment.

To minimize noise pickup and thermal errors, the input traces should be treated like a high-speed differential signal pair and routed tightly together with a direct path to the input pins on the same copper layer. They do not need to be *impedance matched*, but should follow the same matching rules about vias, spacing and equal lengths. The input traces should be run away from noise sources, such as digital lines, switching supplies, or motor drive lines.

Remember that these input traces can contain high voltage (up to 76 V), and should have the appropriate trace routing clearances to other components, traces and layers. Because the sense traces only carry the amplifier bias current, the connecting input traces can be thin traces running close together. This can help with routing or creating the required spacings.

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#### Note

Due to the nature of the device topology, the positive input bias current will vary with  $V_{SENSE}$  with an extra current approximately equivalent to  $V_{SENSE} / 5\text{ k}\Omega$  on top of the typical 12  $\mu\text{A}$  bias current.

---

The negative input bias current is not in the feedback path and will not change over  $V_{SENSE}$ . High or mismatched source impedances should be avoided as this imbalance will create an additional error term over input voltage.

#### 7.4.4.1 Effects of Series Resistance on Sense Lines

While the sense amplifier is depicted as a conventional operational amplifier, it really is based on a current-differencing topology. The input stage uses precision 5-k $\Omega$  resistors internally to convert the voltage on the input pin onto a current, so any resistance added in series with the input pins will change this resistance, and thus the resulting current, causing an error. TI recommends that the total path resistance be less than 10  $\Omega$  and equal to both inputs.

If a resistance is added in series with an input, the gain of that input will not track that of the other input, causing a constant gain error.

TI does not recommend using external resistance to alter the gain, as external resistors do not have the same thermal matching and tracking as the internal thin film resistors. Any added resistance will severely degrade the offset and CMRR specifications.

If resistors are purposely added for filtering, resistance should be added equally to both inputs and be less than 10  $\Omega$ , and the user should be aware that the gain will change slightly.

## 8 Application and Implementation

### Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

### 8.1 Application Information

The LMP8645 device measures the small voltage developed across a current-sensing resistor when current passes through it in the presence of high common-mode voltage. The gain is set by a single resistor and buffered to a single-ended output.

### 8.2 Typical Applications

#### 8.2.1 Typical Current Monitor Application

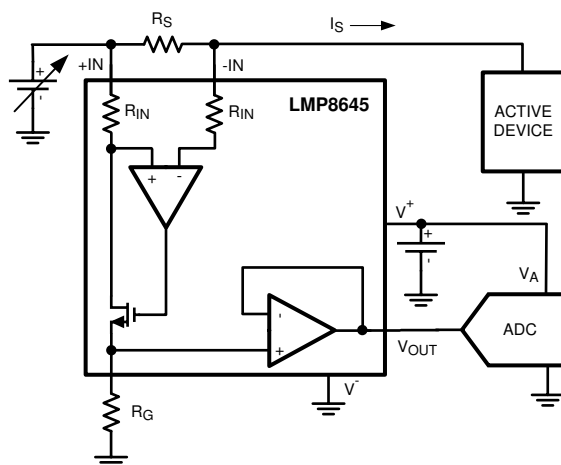


Figure 8-1. LMP8645 in Current Monitor Application

##### 8.2.1.1 Design Requirements

In this example, the LMP8645 is used to monitor the supply current of an active device (Refer to Figure 8-1). The LMP8645 supply voltage is 5 V and the active device is supplied with 12 V. The maximum load current is 1 A.

The LMP8645 will operate in all 3 ranges: in [Range 1](#) when turning on the power of the active device (rising from 0 V to 12 V), while briefly passing through [Range 2](#) as the load supply rises, and finally into [Range 3](#) for normal load operation.

Because the purpose of the application is monitor the current of the active device in any operating condition (power on, normal operation, fault, and so forth), the gain resistor will be selected according to [Range 1](#), the range that puts the most constraints to the maximum output voltage swing of the LMP8645.

##### 8.2.1.2 Detailed Design Procedure

At the start-up of the monitored device, the LMP8645 works at a common-mode voltage of 0 V, which means that the maximum output limit is 1.3 V (Range 1). To maximize the resolution, the  $R_{SENSE}$  value is calculated as maximum allowed  $V_{SENSE}$  (Refer to Figure 7-3) divided by maximum current (1 A), so  $R_{SENSE}=0.5\ \Omega$ .

Due to the output limitation at low common-mode voltage, the maximum allowed gain will be 2.6 V/V, which corresponds to  $R_{GAIN} = 13\ \text{k}\Omega$ . With this approach the current is monitored correctly at any working condition, but does not use the full output swing range of the LMP8645.

Alternatively if the monitored device doesn't sink the full 1 A at any supply voltage, it is possible to design with the full maximum output voltage of the LMP8645 when operating in Range 3 (  $V_{CM} \geq V_S$  ).

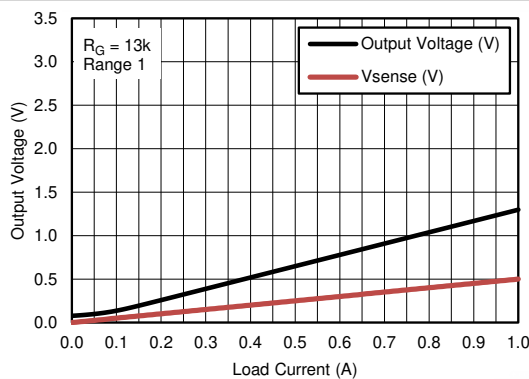
Also in this case it is possible to maximize the resolution using  $R_{sense} = 0.5 \Omega$ , and maximize the output dynamic range with  $R_{GAIN}=33 \text{ k}\Omega$ . With this approach the maximum detectable current, when  $V_{CM}$  is less than 1.8 V, is about 400 mA. While for common-mode voltages of less than 2.5 V the maximum detectable current is 600 mA (Refer to [Figure 7-3](#)), and for common-mode voltages at or above the LMP8645 supply voltage, the maximum current is 1 A.

The second approach maximizes the output dynamic but implies some knowledge on the monitored current.

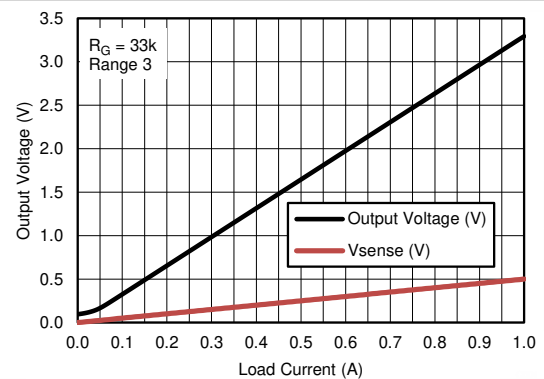
### 8.2.1.3 Application Curves

Figure 8-2 shows the resulting circuit voltages with the input load swept from 0 A to 1 A, with  $R_{\text{GAIN}} = 13 \text{ k}\Omega$  for operation in Range 1 (preferring accuracy over all load operating conditions).

Also shown in [Figure 8-3](#) is the resulting output voltage with  $R_{\text{GAIN}} = 33 \text{ k}\Omega$  for operation in Range 3 (sacrificing low load supply accuracy while optimizing overall resolution at *normal* load operating conditions).



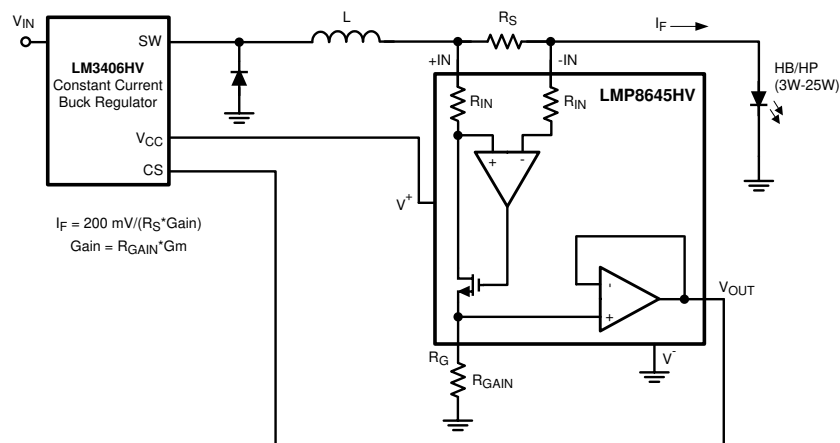
**Figure 8-2. Resulting Input and Output Voltages vs Load Current for Range 1**



**Figure 8-3. Resulting Input and Output Voltages vs Load Current For Range 3**

### 8.2.2 High Brightness LED Driver

The LMP8645 is the right choice in applications which require high-side current sense, such as High Brightness LED for automotive where the cathode of the LED must be connected to the ground (chassis) of the car. In [Figure 8-4](#), the LMP8645 is used to monitor the current High Side in a high brightness LED together with a [LM3406](#) constant current buck regulator LED driver.



### Figure 8-4. High-Side Current Sensing in Driving HP/HB LED

Even though LMP8645 will work in all 3 Ranges,  $R_{GAIN}$  will be calculated according to Range 3 because the purpose is regulating the current in the LEDs when the external MOSFET is OFF (LMP8645 at high  $V_{CM}$ ). Even if this approach makes the LMP8645 able to sense high peak current only in Range 3 where the dynamic output is higher than Range 1 the current resolution is maximized. At each switch ON/OFF of the MOSFET the LMP8645 goes from Range 1 (MOSFET ON, string of LED OFF), to Range 3 (MOSFET OFF, string of LED ON) passing through Range 2 (MOSFET OFF, string of LED OFF). Because the purpose of the application is to sense the current with high precision when the LED string is ON, the  $R_{GAIN}$  will be calculated according to the Range 3.

The LMP8645 supply voltage is supplied by the internal LDO of the LM3406 thorough the pin VCC. The LM340x is expecting a 200-mV feedback signal at the current sense (SNS) pin. The LMP8645 must provide this 200 mV at the determined current limit.

The current which flows through the LED is programmed according to [Equation 8](#):

$$I_F = V_{CS} / (R_S \times \text{Gain}) \quad (8)$$

where:

- $\text{Gain} = R_{GAIN} \times G_m$
- $V_{CS} = 200 \text{ mV}$

In this application the current which flows in the HB LED is in the Range from 350 mA to 1 A, so to reduce the power dissipation on the shunt resistor and have a good accuracy, the  $R_S$  must be in the range from 50 m $\Omega$  and 200 m $\Omega$ . In [Table 8-1](#), two examples are analyzed.

To summarize, calculate the  $R_{GAIN}$  according to the range of operation in which the application mainly works. Once selected, the range considers the more stringent constraint

**Table 8-1. Comparison of Two Ranges**

|                  | $I_F=350 \text{ mA}$ | $I_F=1 \text{ A}$ |
|------------------|----------------------|-------------------|
| $R_{GAIN}$       | 40 k $\Omega$        | 36 k $\Omega$     |
| $R_S$            | 77 m $\Omega$        | 27 m $\Omega$     |
| Dissipated Power | 9.5 mW               | 27 mW             |
| Total Accuracy   | $\approx 5\%$        | $\approx 5\%$     |

## 9 Power Supply Recommendations

To decouple the LMP8645 from AC noise on the power supply, TI recommends using a 0.1- $\mu\text{F}$  bypass capacitor between the  $V_S$  and GND pins. This capacitor must be placed as close as possible to the supply pins. In some cases, an additional 10- $\mu\text{F}$  bypass capacitor may further reduce the supply noise.

## 10 Layout

### 10.1 Layout Guidelines

The traces leading to and from the sense resistor can be significant error sources. With small value sense resistors ( $< 100\text{ m}\Omega$ ), any trace resistance shared with the load current can cause significant errors.

The amplifier inputs should be directly connected to the sense resistor pads using *Kelvin* or *4-wire* connection techniques. The traces should be one continuous piece of copper from the sense resistor pad to the amplifier input pin pad, and ideally on the same copper layer with minimal vias or connectors. This can be important around the sense resistor if it is generating any significant heat gradients.

To minimize noise pick-up and thermal errors, the input traces should be treated like a differential signal pair and routed tightly together with a direct path to the input pins (preferably on the same copper layer). The input traces should be run away from noise sources, such as digital lines, switching supplies or motor drive lines.

Ensure that the sense traces have the appropriate trace routing clearances for the expected load supply voltages.

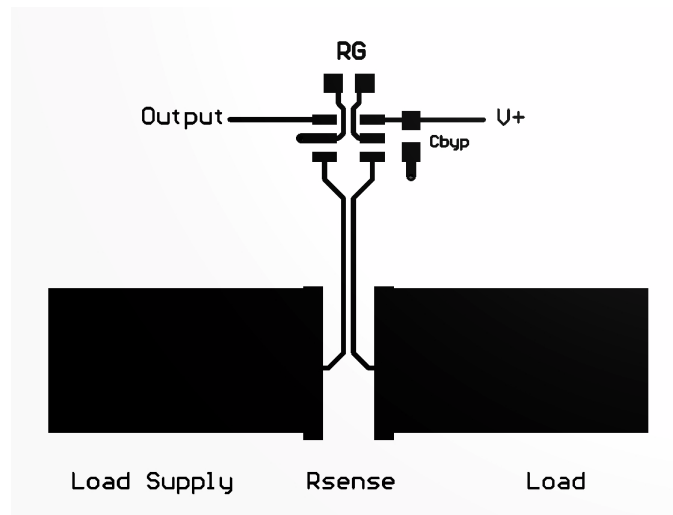
Because the sense traces only carry the amplifier bias current, the connecting input traces can be thinner, signal level traces. Excessive Resistance in the trace should also be avoided.

The paths of the traces should be identical, including connectors and vias, so that any errors will be equal and cancel.

The sense resistor will heat up as the load increases. As the resistor heats up, the resistance generally goes up, which will cause a change in the readings. The sense resistor should have as much heatsinking as possible to remove this heat through the use of heatsinks or large copper areas coupled to the resistor pads.

The gain set resistor pin is a sensitive node and can pick up noise. Keep the gain set resistor close to the  $R_G$  pin and minimize  $R_{GAIN}$  trace length. Connect the grounded end of  $R_{GAIN}$  directly to the LMP8645 ground pin.

### 10.2 Layout Example



**Figure 10-1. Layout Example**

## 11 Device and Documentation Support

### 11.1 Device Support

#### 11.1.1 Development Support

LMP8645 TINA SPICE Model, [SNOM087](#)

TINA-TI SPICE-Based Analog Simulation Program, <http://www.ti.com/tool/tina-ti>

Evaluation Board for the LMP8645, <http://www.ti.com/tool/lmp8645mkeval>

### 11.2 Documentation Support

#### 11.2.1 Related Documentation

For related documentation, see the following:

*AN-1975 LMP8640 / LMP8645 Evaluation Board User Guide*, [SNOA546](#)

### 11.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](#). Click on *Subscribe to updates* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 11.4 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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### 11.6 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### 11.7 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

## 12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

**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="#">LMP8645HVMK/NOPB</a>  | Active        | Production           | SOT-23-THIN (DDC)   6 | 1000   SMALL T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMK/NOPB.A                | Active        | Production           | SOT-23-THIN (DDC)   6 | 1000   SMALL T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMK/NOPB.B                | Active        | Production           | SOT-23-THIN (DDC)   6 | 1000   SMALL T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| <a href="#">LMP8645HVMKE/NOPB</a> | Active        | Production           | SOT-23-THIN (DDC)   6 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMKE/NOPB.A               | Active        | Production           | SOT-23-THIN (DDC)   6 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMKE/NOPB.B               | Active        | Production           | SOT-23-THIN (DDC)   6 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| <a href="#">LMP8645HVMKX/NOPB</a> | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMKX/NOPB.A               | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMKX/NOPB.B               | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMKXNOPBG4                | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMKXNOPBG4.A              | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| LMP8645HVMKXNOPBG4.B              | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AK6A                |
| <a href="#">LMP8645MK/NOPB</a>    | Active        | Production           | SOT-23-THIN (DDC)   6 | 1000   SMALL T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |
| LMP8645MK/NOPB.A                  | Active        | Production           | SOT-23-THIN (DDC)   6 | 1000   SMALL T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |
| LMP8645MK/NOPB.B                  | Active        | Production           | SOT-23-THIN (DDC)   6 | 1000   SMALL T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |
| <a href="#">LMP8645MKE/NOPB</a>   | Active        | Production           | SOT-23-THIN (DDC)   6 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |

| 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) |
|---------------------------------|---------------|----------------------|-----------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| LMP8645MKE/NOPB.A               | Active        | Production           | SOT-23-THIN (DDC)   6 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |
| LMP8645MKE/NOPB.B               | Active        | Production           | SOT-23-THIN (DDC)   6 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |
| <a href="#">LMP8645MKX/NOPB</a> | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |
| LMP8645MKX/NOPB.A               | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |
| LMP8645MKX/NOPB.B               | Active        | Production           | SOT-23-THIN (DDC)   6 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 125   | AJ6A                |

<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.

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## TAPE AND REEL INFORMATION



\*All dimensions are nominal

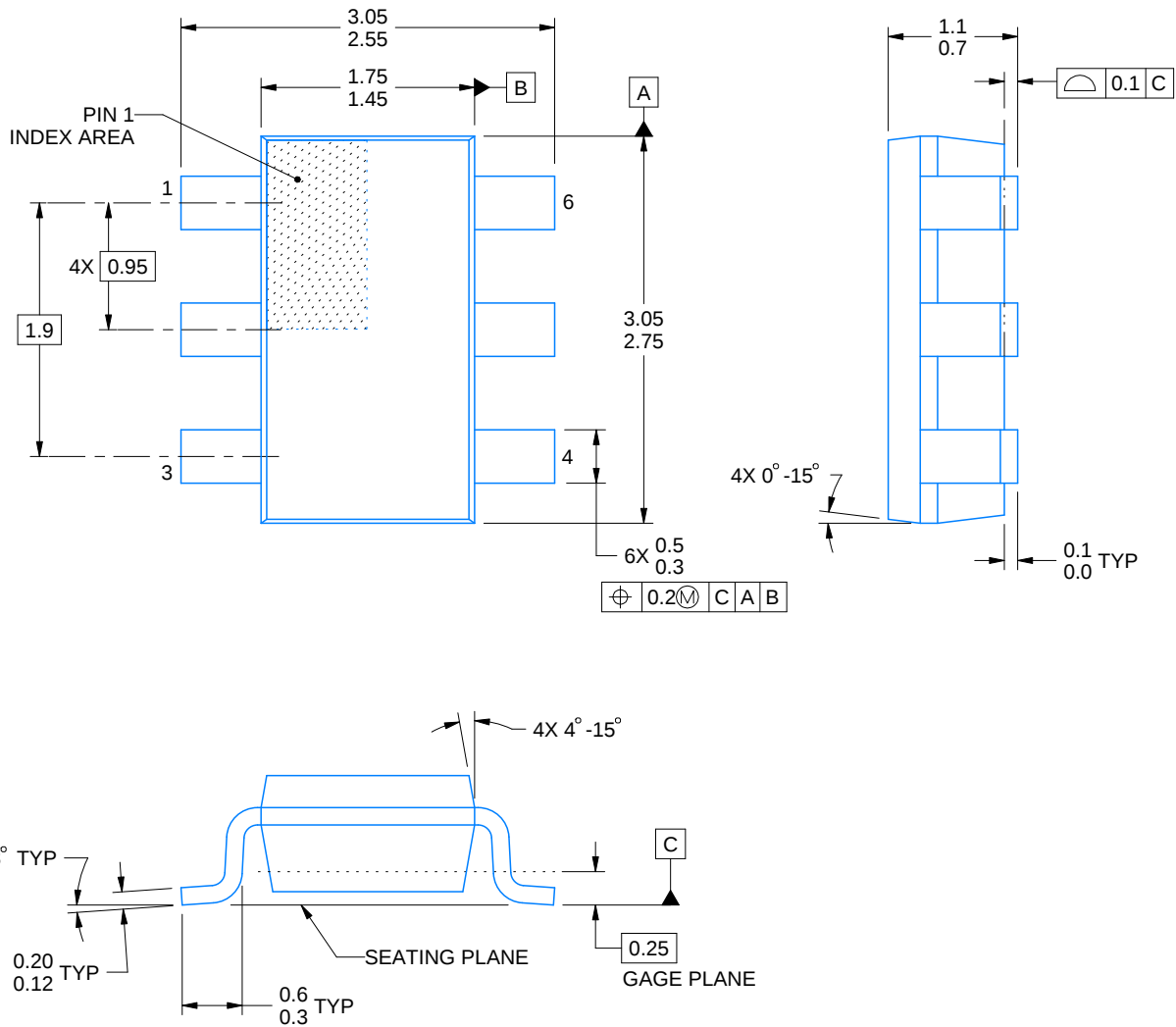
| Device             | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| LMP8645HVMK/NOPB   | SOT-23-THIN  | DDC             | 6    | 1000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP8645HVMKE/NOPB  | SOT-23-THIN  | DDC             | 6    | 250  | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP8645HVMKX/NOPB  | SOT-23-THIN  | DDC             | 6    | 3000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP8645HVMKXNOPBG4 | SOT-23-THIN  | DDC             | 6    | 3000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP8645MK/NOPB     | SOT-23-THIN  | DDC             | 6    | 1000 | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP8645MKE/NOPB    | SOT-23-THIN  | DDC             | 6    | 250  | 178.0              | 8.4                | 3.2     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| LMP8645MKX/NOPB    | SOT-23-THIN  | DDC             | 6    | 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

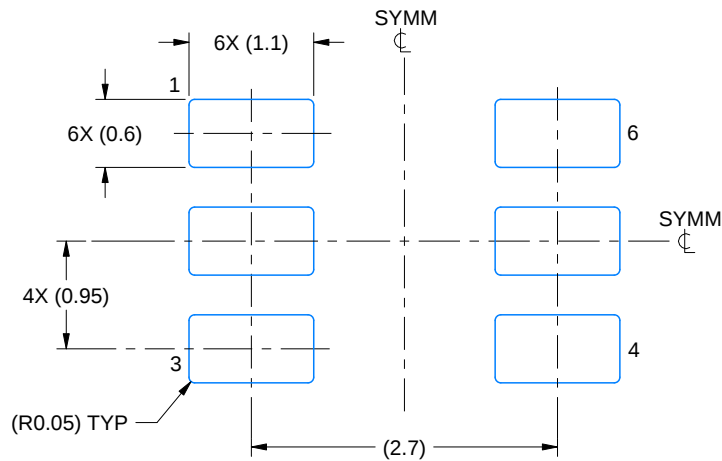
| Device             | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| LMP8645HVMK/NOPB   | SOT-23-THIN  | DDC             | 6    | 1000 | 208.0       | 191.0      | 35.0        |
| LMP8645HVMKE/NOPB  | SOT-23-THIN  | DDC             | 6    | 250  | 208.0       | 191.0      | 35.0        |
| LMP8645HVMKX/NOPB  | SOT-23-THIN  | DDC             | 6    | 3000 | 208.0       | 191.0      | 35.0        |
| LMP8645HVMKXNOPBG4 | SOT-23-THIN  | DDC             | 6    | 3000 | 208.0       | 191.0      | 35.0        |
| LMP8645MK/NOPB     | SOT-23-THIN  | DDC             | 6    | 1000 | 208.0       | 191.0      | 35.0        |
| LMP8645MKE/NOPB    | SOT-23-THIN  | DDC             | 6    | 250  | 208.0       | 191.0      | 35.0        |
| LMP8645MKX/NOPB    | SOT-23-THIN  | DDC             | 6    | 3000 | 208.0       | 191.0      | 35.0        |



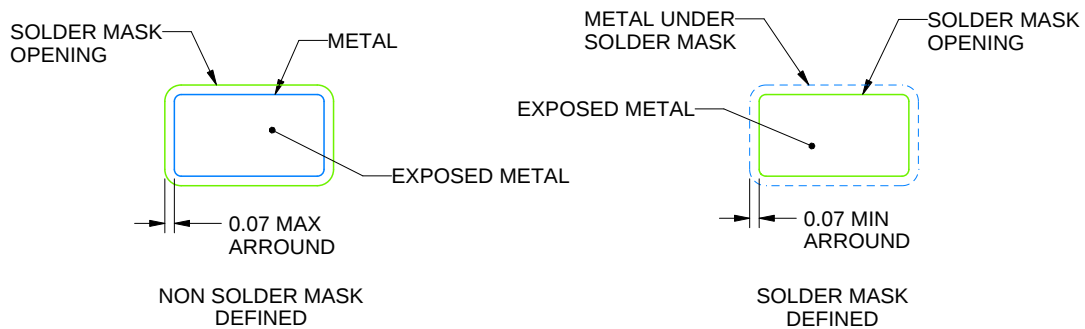
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## NOTES:

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-193.



LAND PATTERN EXAMPLE  
EXPLODED METAL SHOWN  
SCALE:15X



SOLDERMASK DETAILS

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NOTES: (continued)

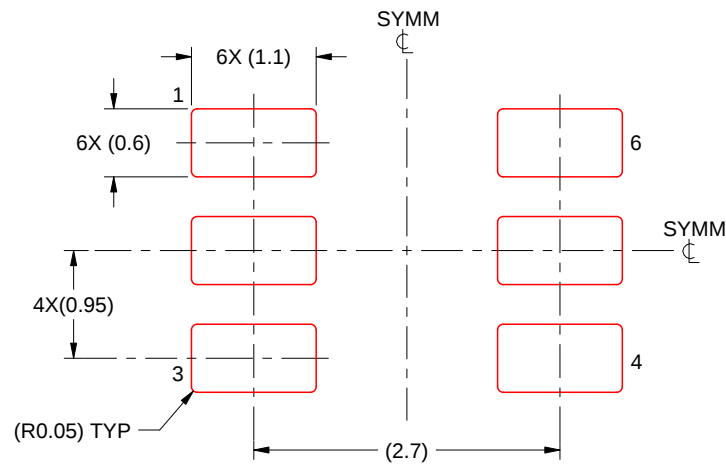
4. Publication IPC-7351 may have alternate designs.
5. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

DDC0006A

SOT-23 - 1.1 max height

SMALL OUTLINE TRANSISTOR



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

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NOTES: (continued)

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

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