# LMP8646 Precision Current Limiter

**Check for Samples: LMP8646, LMP8646HV**

## FEATURES

- **Provides circuit protection and current limiting**
- **Single supply operation**
- **-2V to +76V common mode voltage range**
- **Variable gain set by external resistor**
- **Adjustable bandwidth set by external capacitor**
- **Buffered output**
- **3% output accuracy achievable at $V_{SENSE}$ = 100 mV**

## APPLICATIONS

- **High-side and low-side current limit**
- **Circuit fault protection**
- **Battery and supercap charging**
- **LED constant current drive**
- **Power management**

## DESCRIPTION

The LMP8646 is a precision current limiter used to improve the current limit accuracy of any switching or linear regulator with an available feedback node.

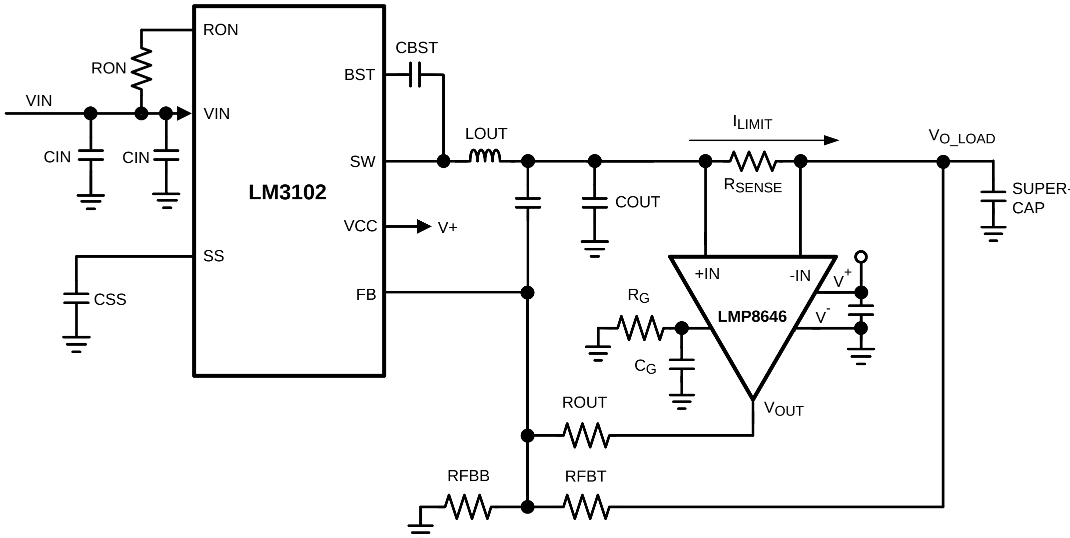
The LMP8646 accepts input signals with a common mode voltage ranging from -2V to 76V. It has a variable gain which is used to adjust the sense current. The gain is configured with a single external resistor, $R_G$, providing a high level of flexibility and accuracy up to 2%. The adjustable bandwidth, which allows the device to be used with a variety of applications, is configurable with a single external capacitor in parallel with $R_G$. In addition, the output is buffered in order to provide a low output impedance.

The LMP8646 is an ideal choice for industrial, automotive, telecommunications, and consumer applications where circuit protection and improved precision systems are required. The LMP8646 is available in a 6-pin TSOT package and can operate at temperature range of −40°C to 125°C.

**Table 1. Key Specifications**

| | VALUE | UNIT |
|---|---|---|
| Supply voltage range | 2.7V to 12 | V |
| Output current (source) | 0 to 5 mA | |
| Gain accuracy | 2.0% (max) | |
| Transconductance | 200 µA/V | |
| Offset | ±1 mV (max) | |
| Quiescent current | 380 µA | |
| Input bias | 12 µA (typ) | |
| PSRR | 85 | dB |
| CMRR | 95 | dB |
| Temperature range | −40°C to 125°C | |
| 6-Pin TSOT Package | | |

## Typical Application




## Connection Diagram

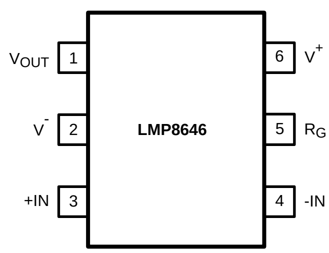
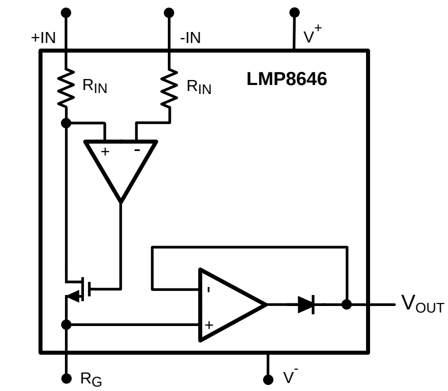



**Figure 1. 6-Pin TSOT Top View**

**Table 2. Pin Descriptions**

| Pin | Name | Description |
|---|---|---|
| 1 | $V_{OUT}$ | Single-Ended Output Voltage |
| 2 | $V^-$ | Negative Supply Voltage. This pin should be connected to ground. |
| 3 | +IN | Positive Input |
| 4 | -IN | Negative Input |
| 5 | $R_G$ | External Gain Resistor. An external capacitance ($C_G$) may be added in parallel with $R_G$ to limit the bandwidth. |
| 6 | $V^+$ | Positive Supply Voltage |

## Block Diagram




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 (1)

| | |
|---|---|
| ESD Tolerance (2) | |
| Human Body Model | |
| For input pins: +IN and -IN | ±4000V |
| For all other pins | ±2000V |
| Machine Model | 200V |
| Charge device model | 1250 |
| Supply Voltage ($V_S = V^+ - V^-$) | 13.2V |
| Differential voltage +IN- (-IN) | 6V |
| Voltage at pins +IN, -IN | -6V to 80V |
| Voltage at $R_G$ pin | 13.2V |
| Voltage at OUT pin | $V^-$ to $V^+$ |
| Storage Temperature Range | -65°C to 150°C |
| Junction Temperature (3) | 150°C |
| For soldering specifications, see product folder at www.national.com and www.national.com/ms/MS/MS-SOLDERING.pdf | |

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics Tables.
(2) 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).
(3) The maximum power dissipation must be derated at elevated temperatures and is dictated by $T_{J(MAX)}$, $\theta_{JA}$, and the ambient temperature, $T_A$. The maximum allowable power dissipation $P_{DMAX} = (T_{J(MAX)} - T_A)/ \theta_{JA}$ or the number given in Absolute Maximum Ratings, whichever is lower.

## Operating Ratings (1)

| | |
|---|---|
| Supply Voltage ($V_S = V^+ - V^-$) | 2.7V to 12V |
| Temperature Range (2) | -40°C to 125°C |
| Package Thermal Resistance (2) | |

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics Tables.
(2) The maximum power dissipation must be derated at elevated temperatures and is dictated by $T_{J(MAX)}$, $\theta_{JA}$, and the ambient temperature, $T_A$. The maximum allowable power dissipation $P_{DMAX} = (T_{J(MAX)} - T_A)/ \theta_{JA}$ or the number given in Absolute Maximum Ratings, whichever is lower.

## Operating Ratings [1] (continued)

| | |
|---|---|
| TSOT-6 | 96°C/W |

## 2.7V Electrical Characteristics (1)

Unless otherwise specified, all limits guaranteed for at $T_A$ = 25°C, $V_S$=($V^+$ – $V^-$) = (2.7V - 0V) = 2.7 V, −2V < $V_{CM}$ < 76V, $R_G$= 25kΩ, $R_L$ = 10 kΩ. **Boldface** limits apply at the temperature extremes.

| Symbol | Parameter | Condition | Min (2) | Typ (3) | Max (2) | Units |
|---|---|---|---|---|---|---|
| $V_{OFFSET}$ | Input Offset Voltage | $V_{CM}$ = 2.1V | -1<br>**-1.7** | | 1<br>**1.7** | mV |
| $TCV_{OS}$ | Input Offset Voltage Drift (4) (5) | $V_{CM}$ = 2.1V | | | 7 | μV/°C |
| $I_B$ | Input Bias Current (6) | $V_{CM}$ = 2.1V | | 12 | 20 | μA |
| $e_{ni}$ | Input Voltage Noise (5) | f > 10 kHz, $R_G$ = 5 kΩ | | 120 | | $nV/\sqrt{Hz}$ |
| $V_{SENSE}$ | Max Input Sense Voltage (5) | $V_{CM}$ = 12V, $R_G$ = 5 kΩ | | | 600 | mV |
| Gain $A_V$ | Adjustable Gain Setting (5) | $V_{CM}$ = 12V | 1 | | 100 | V/V |
| Gm | Transconductance = 1/$R_{IN}$ | $V_{CM}$ = 2.1V | | 200 | | μA/V |
| | Accuracy | $V_{CM}$ = 2.1V | -2<br>**-3.4** | | 2<br>**3.4** | % |
| | Gm drift (5) | −40°C to 125°C, $V_{CM}$=2.1V | | | **140** | ppm /°C |
| PSRR | Power Supply Rejection Ratio | $V_{CM}$ = 2.1V, 2.7V < $V^+$ < 12V, | 85 | | | dB |
| CMRR | Common Mode Rejection Ratio | 2.1V < $V_{CM}$ < 76V | 95 | | | dB |
| | | -2V <$V_{CM}$ < 2.1V, | 55 | | | |
| SR | Slew Rate (7) (5) | $V_{CM}$ = 5V, $C_G$ = 4 pF, $V_{SENSE}$ from 25 mV to 175 mV, $C_L$ = 30 pF, $R_L$ = 1MΩ | | 0.5 | | V/μs |
| $I_S$ | Supply Current | $V_{CM}$ = 2.1V | | 380 | 610<br>**807** | uA |
| | | $V_{CM}$ = −2V | | 2000 | 2500<br>**2700** | |
| $V_{OUT}$ | Maximum Output Voltage | $V_{CM}$ = 2.1V, $R_G$ = 500 kΩ | 1.1 | | | V |
| | Minimum Output Voltage | $V_{CM}$ = 2.1V | | | 20 | mV |
| | Maximum Output Voltage | VS = $V_{CM}$ = 3.3V, $R_G$ = 500 kΩ | 1.6 | | | V |
| | Minimum Output Voltage | VS = $V_{CM}$ = 3.3V, $R_G$ = 500 kΩ | | | 22 | mV |
| $I_{OUT}$ | Output current (5) | Sourcing, $V_{OUT}$= 600mV, $R_G$ = 150kΩ | | 5 | | mA |
| $C_{LOAD}$ | Max Output Capacitance Load (5) | | | 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 guarantee of parametric performance is indicated in the electrical tables under conditions of internal self-heating where $T_J$ > $T_A$.
(2) All limits are guaranteed by testing, design, or statistical analysis.
(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 guaranteed on shipped production material.
(4) Offset voltage temperature drift is determined by dividing the change in $V_{OS}$ at the temperature extremes by the total temperature change.
(5) This parameter is guaranteed by design and/or characterization and is not tested in production.
(6) Positive Bias Current corresponds to current flowing into the device.
(7) The number specified is the average of rising and falling slew rates and measured at 90% to 10%.

## 5V Electrical Characteristics [1]

Unless otherwise specified, all limits guaranteed for at $T_A$ = 25°C, $V_S$=$V^+$-$V^-$, $V^+$ = 5V, $V^-$ = 0V, −2V < $V_{CM}$ < 76V, $R_g$= 25kΩ, $R_L$ = 10 kΩ. **Boldface** limits apply at the temperature extremes.

| Symbol | Parameter | Condition | Min [2] | Typ [3] | Max [2] | Units |
|---|---|---|---|---|---|---|
| $V_{OFFSET}$ | Input Offset Voltage | $V_{CM}$ = 2.1V | -1<br>**-1.7** | | 1<br>**1.7** | mV |
| $TCV_{OS}$ | Input Offset Voltage Drift [4] [5] | $V_{CM}$ = 2.1V | | | 7 | μV/°C |
| $I_B$ | Input Bias Current [6] | $V_{CM}$ = 2.1V | | 12.5 | 22 | μA |
| $e_{ni}$ | Input Voltage Noise [5] | f > 10 kHz, $R_G$ = 5 kΩ | | 120 | | nV/$\sqrt{Hz}$ |
| $V_{SENSE(MAX)}$ | Max Input Sense Voltage [5] | $V_{CM}$ = 12V, $R_G$ = 5 kΩ | | 600 | | mV |
| Gain $A_V$ | Adjustable Gain Setting [5] | $V_{CM}$ = 12V | 1 | | 100 | V/V |
| Gm | Transconductance = 1/$R_{IN}$ | $V_{CM}$ = 2.1V | | 200 | | μA/V |
| | Accuracy | $V_{CM}$ = 2.1V | -2<br>**-3.4** | | 2<br>**3.4** | % |
| | Gm drift [5] | −40°C to 125°C, $V_{CM}$= 2.1V | | | 140 | ppm /°C |
| PSRR | Power Supply Rejection Ratio | $V_{CM}$ = 2.1V, 2.7V < $V^+$ < 12V, | 85 | | | dB |
| CMRR | Common Mode Rejection Ratio | 2.1V <$V_{CM}$ < 76V | 95 | | | dB |
| | | -2V < $V_{CM}$ < 2.1V | 55 | | | |
| SR | Slew Rate [7] [5] | $V_{CM}$ = 5V, $C_G$ = 4 pF, $V_{SENSE}$ from 100 mV to 500 mV, $C_L$ = 30 pF, $R_L$= 1MΩ | | 0.5 | | V/μs |
| $I_S$ | Supply Current | $V_{CM}$ = 2.1V | | 450 | 660<br>**939** | uA |
| | | $V_{CM}$ = −2V | | 2100 | 2800<br>**3030** | |
| $V_{OUT}$ | Maximum Output Voltage | $V_{CM}$ =5V, $R_G$= 500 kΩ | 3.3 | | | V |
| | Minimum Output Voltage | $V_{CM}$ =2.1V | | | 22 | mV |
| $I_{OUT}$ | Output current [5] | Sourcing, $V_{OUT}$= 1.65V, $R_G$ = 150kΩ | | 5 | | mA |
| $C_{LOAD}$ | Max Output Capacitance Load [5] | | | 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 guarantee of parametric performance is indicated in the electrical tables under conditions of internal self-heating where $T_J$ > $T_A$.
(2) All limits are guaranteed by testing, design, or statistical analysis.
(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 guaranteed on shipped production material.
(4) Offset voltage temperature drift is determined by dividing the change in $V_{OS}$ at the temperature extremes by the total temperature change.
(5) This parameter is guaranteed by design and/or characterization and is not tested in production.
(6) Positive Bias Current corresponds to current flowing into the device.
(7) The number specified is the average of rising and falling slew rates and measured at 90% to 10%.

## 12V Electrical Characteristics [1]

Unless otherwise specified, all limits guaranteed for at $T_A$ = 25°C, $V_S$=$V^+$-$V^-$, $V^+$ = 12V, $V^-$ = 0V, −2V < $V_{CM}$ < 76V, $R_g$= 25kΩ, $R_L$ = 10 kΩ. **Boldface** limits apply at the temperature extremes.

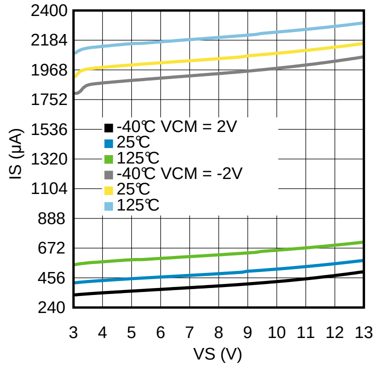
| Symbol | Parameter | Condition | Min [2] | Typ [3] | Max [2] | Units |
|---|---|---|---|---|---|---|
| $V_{OFFSET}$ | Input Offset Voltage | $V_{CM}$ = 2.1V | -1<br>**-1.7** | | 1<br>**1.7** | mV |
| $TCV_{OS}$ | Input Offset Voltage Drift [4] [5] | $V_{CM}$ = 2.1V | | | 7 | µV/°C |
| $I_B$ | Input Bias Current [6] | $V_{CM}$ = 2.1V | | 13 | 23 | µA |
| $e_{ni}$ | Input Voltage Noise [5] | f > 10 kHz, $R_G$ = 5 kΩ | | 120 | | $nV/\sqrt{Hz}$ |
| $V_{SENSE(MAX)}$ | Max Input Sense Voltage [5] | $V_{CM}$ =12V, $R_G$ = 5 kΩ | | 600 | | mV |
| Gain $A_V$ | Adjustable Gain Setting [5] | $V_{CM}$ = 12V | 1 | | 100 | V/V |
| Gm | Transconductance = 1/$R_{IN}$ | $V_{CM}$ = 2.1V | | 200 | | µA/V |
| | Accuracy | $V_{CM}$ = 2.1V | -2<br>**-3.4** | | 2<br>**3.4** | % |
| | Gm drift [5] | −40°C to 125°C, $V_{CM}$ =2.1V | | | 140 | ppm /°C |
| PSRR | Power Supply Rejection Ratio | $V_{CM}$ = 2.1V, 2.7V <$V^+$ < 12V, | 85 | | | dB |
| CMRR | Common Mode Rejection Ratio | 2.1V <$V_{CM}$ < 76V | 95 | | | dB |
| | | –2V <$V_{CM}$ < 2.1V | 55 | | | |
| SR | Slew Rate [7] [5] | $V_{CM}$ = 5V, $C_G$ = 4 pF, $V_{SENSE}$ from 100 mV to 500 mV, $C_L$ = 30 pF, $R_L$=1MΩ | | 0.6 | | V/µs |
| $I_S$ | Supply Current | $V_{CM}$ = 2.1V | | 555 | 845<br>**1123** | uA |
| | | $V_{CM}$ = −2V | | 2200 | 2900<br>**3110** | |
| $V_{OUT}$ | Maximum Output Voltage | $V_{CM}$ = 12V, $R_G$= 500kΩ, | 10 | | | V |
| | Minimum Output Voltage | $V_{CM}$ = 2.1V | | | 24 | mV |
| $I_{OUT}$ | Output current [5] | Sourcing, $V_{OUT}$= 5.25V, $R_G$ = 150kΩ | | 5 | | mA |
| $C_{LOAD}$ | Max Output Capacitance Load [5] | | | 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 guarantee of parametric performance is indicated in the electrical tables under conditions of internal self-heating where $T_J$ > $T_A$.
(2) All limits are guaranteed by testing, design, or statistical analysis.
(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 guaranteed on shipped production material.
(4) Offset voltage temperature drift is determined by dividing the change in $V_{OS}$ at the temperature extremes by the total temperature change.
(5) This parameter is guaranteed by design and/or characterization and is not tested in production.
(6) Positive Bias Current corresponds to current flowing into the device.
(7) The number specified is the average of rising and falling slew rates and measured at 90% to 10%.

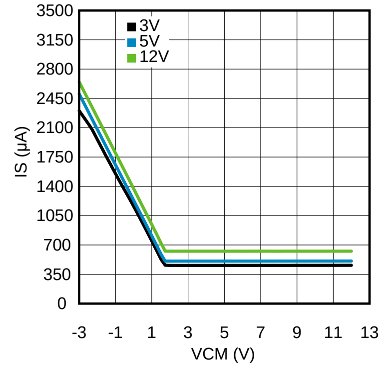
## Typical Performance Characteristics

Unless otherwise specified: $T_A$ = 25°C, $V_S$=$V^+$-$V^-$, $V_{SENSE}$= +IN - (-IN), $R_L$ = 10 kΩ.

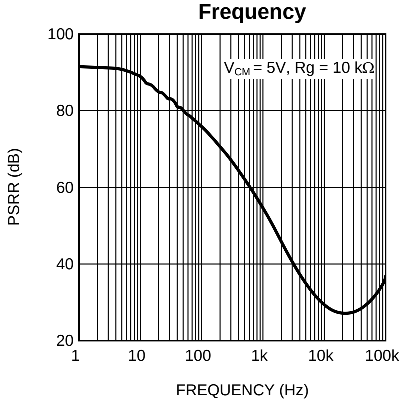
**Supply Current vs. Supply Voltage for $V_{CM}$ = 2V**



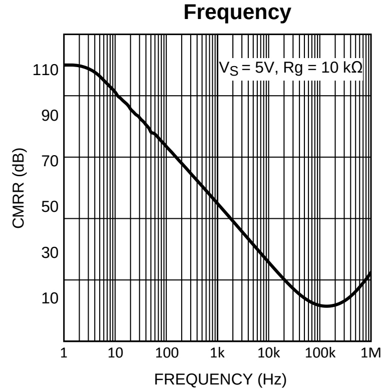

**Supply Current vs. $V_{CM}$**



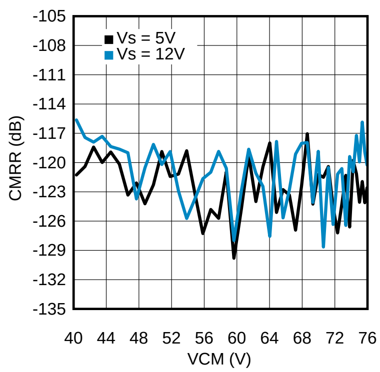

**AC PSRR vs. Frequency**



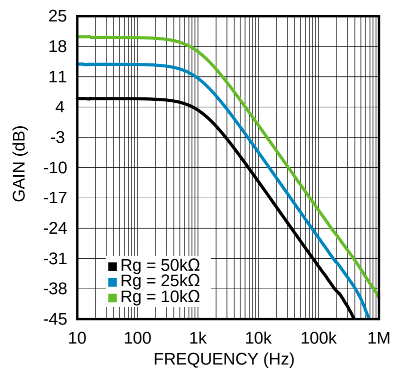

**AC CMRR vs. Frequency**




**CMRR vs. High $V_{CM}$**



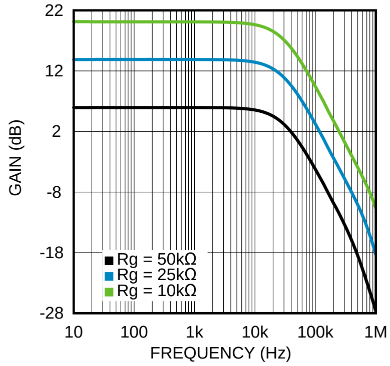

**Gain vs. Frequency (BW = 1kHz)**



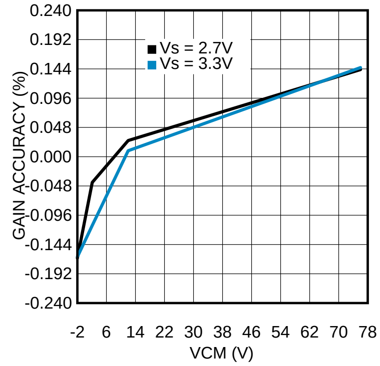
## Typical Performance Characteristics (continued)

Unless otherwise specified: $T_A$ = 25°C, $V_S$=$V^+$-$V^-$, $V_{SENSE}$= +IN - (-IN), $R_L$ = 10 kΩ.

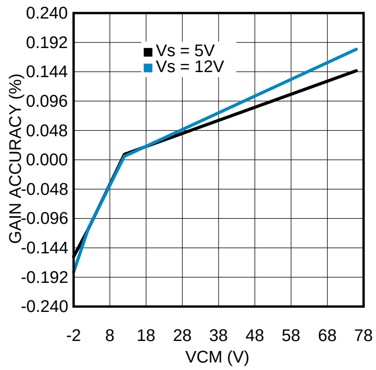
**Gain vs. Frequency (BW = 35kHz)**



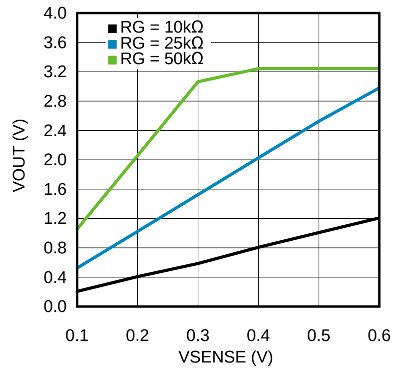

**Gain Accuracy vs. $V_{CM}$**



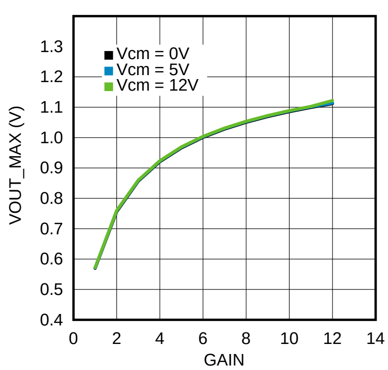

**Gain Accuracy vs. $V_{CM}$**



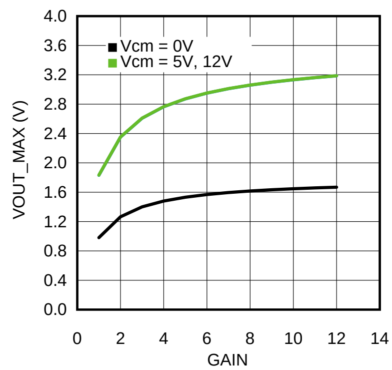

**$V_{OUT}$ vs. $V_{SENSE}$**




**$V_{OUT\_MAX}$ vs. Gain at Vs = 2.7V**



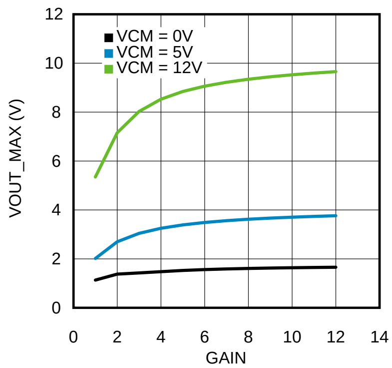

**$V_{OUT\_MAX}$ vs. Gain at Vs = 5.0V**



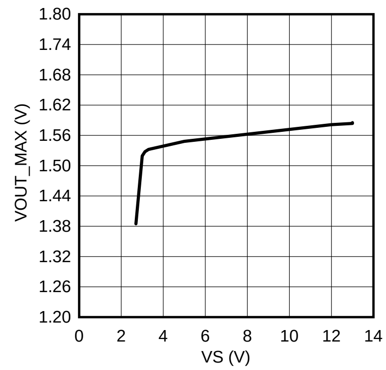
## Typical Performance Characteristics (continued)

Unless otherwise specified: $T_A$ = 25°C, $V_S$=$V^+$-$V^-$, $V_{SENSE}$= +IN - (-IN), $R_L$ = 10 kΩ.

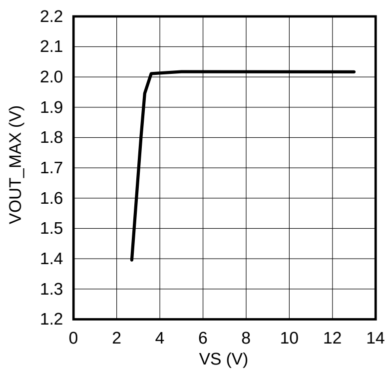
$V_{OUT\_MAX}$ vs. Gain at Vs = 12V



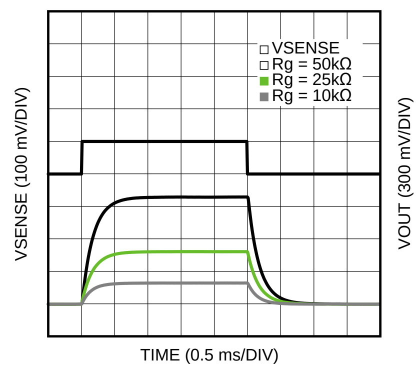

$V_{OUT\_MAX}$ vs. $V_S$ at $V_{CM}$ = -2V



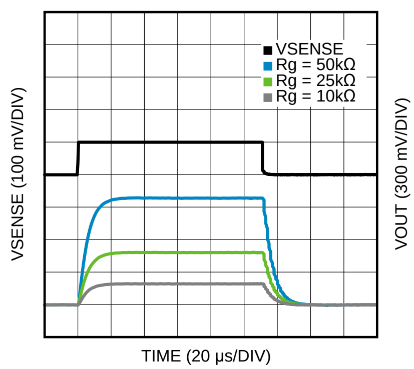

$V_{OUT\_MAX}$ vs. $V_S$ at $V_{CM}$ = 2.1V



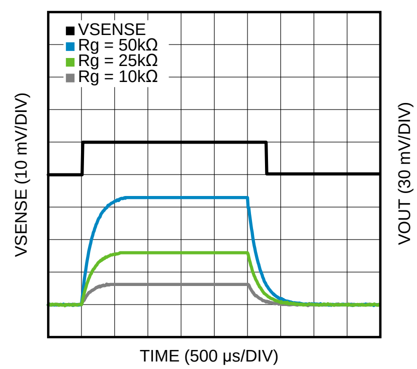

**Large Step Response at BW = 1kHz**




**Large Step Response at BW = 35 kHz**



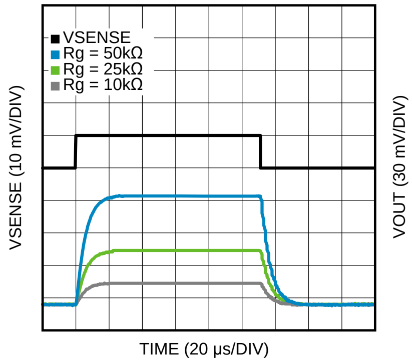

**Small Step Response at BW = 1 kHz**



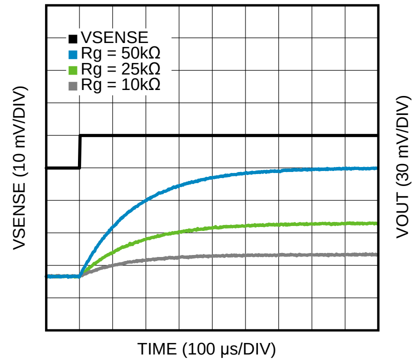
## Typical Performance Characteristics (continued)

Unless otherwise specified: $T_A$ = 25°C, $V_S$=V⁺-V⁻, $V_{SENSE}$= +IN - (-IN), $R_L$ = 10 kΩ.

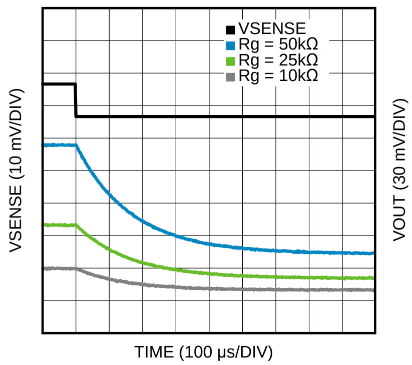
**Small Step Response at BW = 35 kHz**



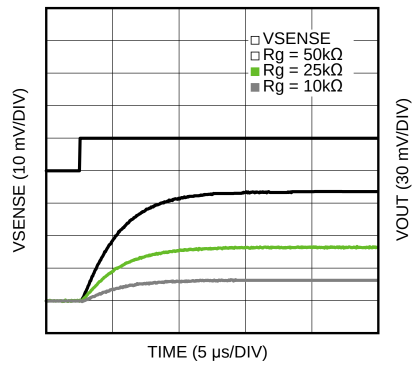

**Settling Time (Rise) at 1kHz**



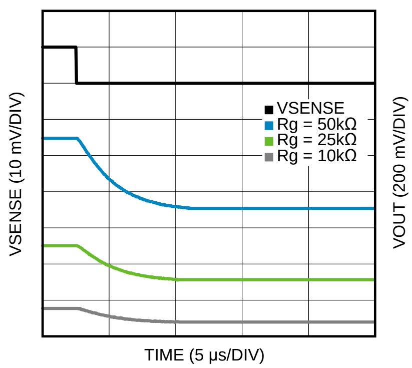

**Settling Time (Fall) at 1kHz**



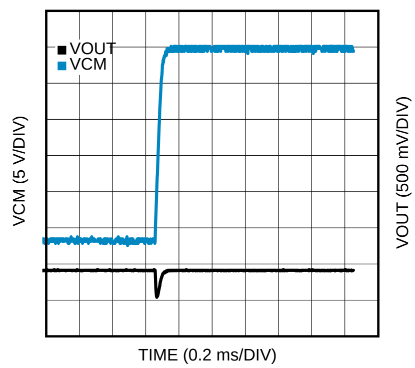

**Settling Time (Rise) at 35kHz**



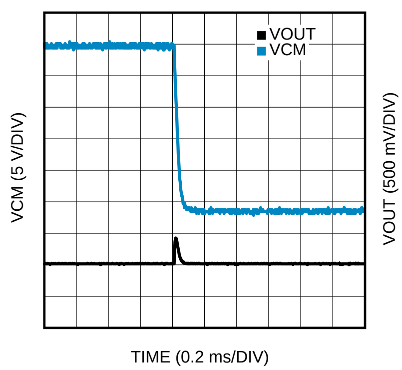

**Settling Time (Fall) at 35kHz**




**Common Mode Step Response (Rise) at 35 kHz**




**Common Mode Step Response (Fall) at 35 kHz**



# FUNCTIONAL DESCRIPTION

## GENERAL

The LMP8646 is a single supply precision current limiter with variable gain selected through an external resistor ($R_G$) and a variable bandwidth selected through an external capacitor ($C_G$) in parallel with $R_G$. Its common-mode of operation is -2V to +76V, and the LMP8646 has an buffered output to provide a low output impedance. More details of the LMP8646's functional description can be seen in the following subsections.

## THEORY OF OPERATION

As seen from Figure 2, the sense current flowing through $R_{SENSE}$ develops a voltage drop equal to $V_{SENSE}$. The high impedance inputs of the amplifier does not conduct this current and the high open loop gain of the sense amplifier forces its non-inverting input to the same voltage as the inverting input. In this way the voltage drop across $R_{IN}$ matches $V_{SENSE}$. The current $I_{IN}$ flowing through $R_{IN}$ has the following equation:

$$I_{IN} = V_{SENSE}/ R_{IN} = R_{SENSE}*I_{SENSE}/R_{IN} \quad (1)$$

$$\text{where } R_{IN} = 1/Gm = 1/(200\ \mu A/V) = 5\ kOhm \quad (2)$$

$I_{IN}$ flows entirely across the external gain resistor $R_G$ to develop a voltage drop equal to:

$$V_{RG} = I_{IN}*R_G = (V_{SENSE}/R_{IN}) *R_G = [(R_{SENSE}*I_{SENSE}) / R_{IN}]*R_G \quad (3)$$

This voltage is buffered and showed at the output with a very low impedance allowing a very easy interface of the LMP8646 with the feedback of many voltage regulators. This output voltage has the following equation:

$$V_{OUT} = V_{RG} = [(R_{SENSE}*I_{SENSE}) / R_{IN}]*R_G \quad (4)$$

$$V_{OUT} = V_{SENSE}* R_G/R_{IN} \quad (5)$$

$$V_{OUT} = V_{SENSE}* R_G/(5\ kOhm) \quad (6)$$

$$V_{OUT} = V_{SENSE}* \text{Gain, where Gain} = R_G/R_{IN} \quad (7)$$

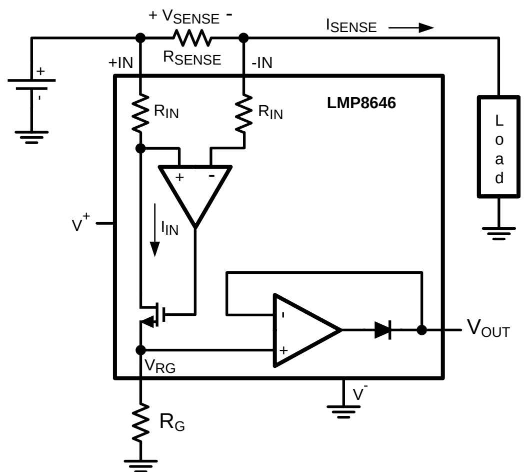



**Figure 2. Current monitor**

### *MAXIMUM OUTPUT VOLTAGE, $V_{OUT\_MAX}$*

The maximum output voltage, $V_{OUT\_MAX}$, depends on the supply voltage, $V_S = V^+ - V^-$, and on the common mode voltage, $V_{CM}$ = (+IN + -IN) / 2.

The following subsections show three cases to calculate for $V_{OUT\_MAX}$.

**Case 1: −2V < $V_{CM}$ < 1.8V, and $V_S$ > 2.7V**

If $V_S \geq 5$ V,

then $V_{OUT\_MAX}$ = 1.3V.

Else if Vs = 2.7V,

then $V_{OUT\_MAX}$ = 1.1V.

**Case 2: 1.8V < $V_{CM}$ < $V_S$, and $V_S$ > 3.3V**

In this case, $V_X$ is a fixed value that depends on the supply voltage. $V_X$ has the following values:

If $V_S$ = 12V, then $V_X$ = 10V.

Else if $V_S$ = 5V, then $V_X$ = 3.3V .

Else if $V_S$ = 2.7V, then $V_X$ = 1.1V.

If $V_X \leq (V_{CM} - V_{SENSE} - 0.25)$ ,

then $V_{OUT\_MAX} = V_X$.

Else,

$V_{OUT\_MAX} = (V_{CM} - V_{SENSE} - 0.25)$.

For example, if $V_{CM}$ = 4V, $V_S$ = 5V (and thus $V_X$ = 3.3V), $V_{SENSE}$ = 0.1 V, then $V_{OUT\_MAX}$ = 3.3V because 3.3V ≤ (4 - 0.1 - 0.25).

**Case 3: $V_{CM}$ > $V_S$, and $V_S$ > 2.7V**

If $V_S$ = 12V, then $V_{OUT\_MAX}$ = 10V.

Else if $V_S$ = 5V, then $V_{OUT\_MAX}$ = 3.3V .

Else if $V_S$ = 2.7V, then $V_{OUT\_MAX}$ = 1.1V.

## APPLICATIONS INFORMATION

### *OUTPUT ACCURACY*

The output accuracy is the device error contributed by the LMP8646 based on its offset and gain errors. The LMP8646 output accuracy has the following equations:

$$\text{Output Accuracy} = \left| \frac{V_{OUT\_THEO} - V_{OUT\_CAL}}{V_{OUT\_THEO}} \right| \times 100(\%)$$

$$\text{where } V_{OUT\_THEO} = (V_{SENSE}) \times \frac{R_G}{1/Gm}$$

$$\text{and } V_{OUT\_CALC} = \frac{(V_{SENSE} + V_{OFFSET}) \times R_G}{1/[Gm\ (1 + Gm\_Accuracy)]}$$

**Figure 3. Output Accuracy Equations**

For example, assume $V_{SENSE}$ = 100 mV, $R_G$ = 10 kOhm, and it is known that $V_{OFFSET}$ = 1 mV and Gm_Accuracy = 2% (Electrical Characteristics Table), then the output accuracy can be calculated as:

$$V_{OUT\_THEO} = (100\ mV) \times \frac{10\ k\Omega}{1/(200\mu)} = 0.2V$$

$$V_{OUT\_CALC} = \frac{(100\ mV + 1\ mV) \times 10\ k\Omega}{1/[200\mu\ (1 + 2/100)]} = 0.20604V$$

$$\text{Output Accuracy} = \left|\frac{0.2V - 0.20604V}{0.2V}\right| \times 100 = 3.02\%$$

**Figure 4. Output Accuracy Example**

In fact, as $V_{SENSE}$ decreases, the output accuracy worsens as seen in Figure 5. These equations provide a valuable tool to estimate how the LMP8646 affects the overall system performance. Knowing this information allows the system designer to pick the appropriate external resistances ($R_{SENSE}$ and $R_G$) to adjust for the tolerable system error. Examples of this tolerable system error can be seen in the next sections.

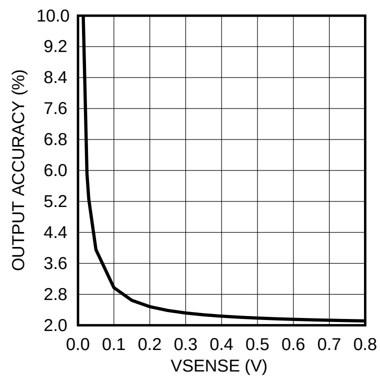



**Figure 5. Output Accuracy vs. $V_{SENSE}$**

### *SELECTION OF THE SENSE RESISTOR, $R_{SENSE}$*

The accuracy of the current measurement also depends on the value of the shunt resistor $R_{SENSE}$. Its value depends on the application and is a compromise between small-signal accuracy and maximum permissible voltage loss in the load line.

$R_{SENSE}$ is directly proportional to $V_{SENSE}$ through the equation $R_{SENSE} = (V_{SENSE}) / (I_{SENSE})$. If $V_{SENSE}$ is small, then there is a smaller voltage loss in the load line, but the output accuracy is worse because the LMP8646 offset error will contribute more. Therefore, high values of $R_{SENSE}$ provide better output accuracy by minimizing the effects of offset, while low values of $R_{SENSE}$ minimize the voltage loss in the load line. For most applications, best performance is obtained with an $R_{SENSE}$ value that provides a $V_{SENSE}$ of 100 mV to 200 mV.

### $R_{SENSE}$ Consideration for System Error

The output accuracy described in the previous section talks about the error contributed just by the LMP8646. The system error, however, consists of the errors contributed by the LMP8646 as well as other external resistors such as $R_{SENSE}$ and $R_G$. Let's rewrite the output accuracy equation for the system error assuming that $R_{SENSE}$ is non-ideal and $R_G$ is ideal. This equation can be seen as:

$$\text{System Error} = \left|\frac{V_{OUT\_THEO} - V_{OUT\_CAL}}{V_{OUT\_THEO}}\right| \times 100(\%)$$

$$\text{where } V_{OUT\_THEO} = (R_{SENSE} \times I_{SENSE}) \times \frac{R_G}{1/Gm}$$

$$\text{and } V_{OUT\_CALC} = \frac{[R_{SENSE}\ (1+\text{Tolerance}) \times I_{SENSE} + V_{OFFSET}] \times R_G}{1/[Gm\ (1 + Gm\_Accuracy)]}$$

**Figure 6. System Error Equation Assuming $R_{SENSE}$ is Non-ideal and $R_G$ is Ideal**

Continuing from the previous output accuracy example, we can calculate for the system error assuming that $R_{SENSE}$ = 100 mOhm (with 1% tolerance), $I_{SENSE}$ = 1A, and $R_G$ = 10 kOhm. From the Electrical Characteristics Table, it is also known that $V_{OFFSET}$ = 1 mV and Gm_Accuracy = 2%.

$$V_{OUT\_THEO} = (100\ m\Omega \times 1A) \times \frac{10\ k\Omega}{1/(200\mu)} = 0.2V$$

$$V_{OUT\_CALC} = \frac{[100\ m\Omega\ (1+1/100) \times 1A + 1mV] \times 10\ k\Omega}{1/[200\mu\ (1 + 2/100)]} = 0.20808V$$

$$\text{System Error} = \left|\frac{0.2V - 0.20808V}{0.2V}\right| \times 100 = 4.04\%$$

**Figure 7. System Error Example Assuming $R_{SENSE}$ is Non-ideal and $R_G$ is Ideal**

Because an $R_{SENSE}$ tolerance will increase the system error, we recommend selecting an $R_{SENSE}$ resistor with low tolerance.

### SELECTION OF THE GAIN RESISTOR, $R_G$

For the LMP8646, the gain is selected through an external resistor connected to the $R_G$ pin. The voltage at this $R_G$ pin is equal to $V_{OUT}$, which has the equation $V_{OUT} = V_{RG} = V_{SENSE} * R_G/(5\ kOhm)$.

In fact, $R_G$ must be chosen such that the $V_{OUT}$ does not exceed its maximum ratings ($V_{OUT\_MAX}$) as described in the MAXIMUM OUTPUT VOLTAGE, $V_{OUT\_MAX}$ section. Using this $V_{OUT\_MAX}$ and the equation $R_{G\_MAX} = (V_{OUT\_MAX} * 5kOhm) / (V_{SENSE})$, a plot of $R_{G\_MAX}$ vs. $V_{SENSE}$ can be seen for three cases below. Use these plots to help select the appropriate $R_G$ value so that $V_{SENSE}$ and $V_{OUT}$ stay within the recommended operating ratings. Since these plots are for $R_{G\_MAX}$, all of the combinations of $R_G$ below the curve are allowed.

#### Case 1: −2V < $V_{CM}$ < 1.8V, and $V_S$ > 3.3V

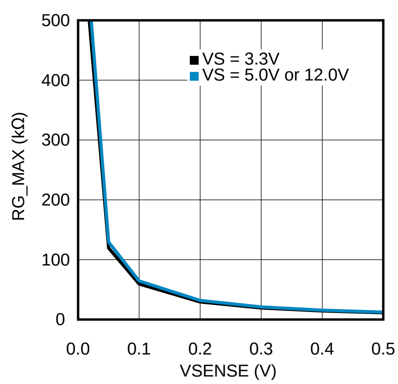



**Figure 8. Allowed $R_G$ for CASE 1**

#### Case 2: 1.8V < $V_{CM}$ < $V_S$, and $V_S$ > 3.3V

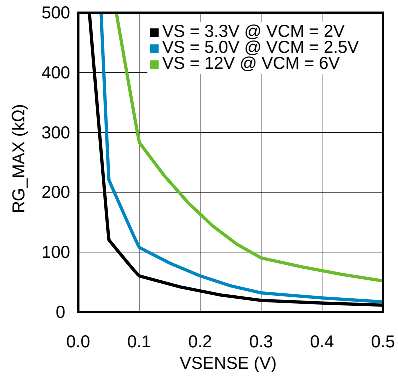



**Figure 9. Allowed $R_G$ for CASE 2**

### Case 3: $V_{CM} > V_S$, and $V_S > 3.3V$

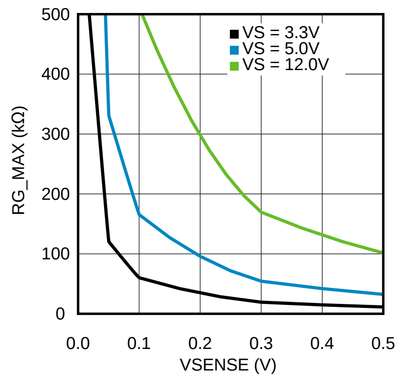



**Figure 10. Allowed $R_G$ for CASE 3**

## $R_G$ Consideration for System Error

The previous section discussed the system error assuming that $R_{SENSE}$ is non-ideal and $R_G$ is ideal. This section expands the system error equation by assuming that both $R_{SENSE}$ and $R_G$ are non-ideal. This system error equation can be rewritten as:

$$\text{System Error} = \left| \frac{V_{OUT\_THEO} - V_{OUT\_CAL}}{V_{OUT\_THEO}} \right| \times 100(\%)$$

$$\text{where } V_{OUT\_THEO} = (R_{SENSE} \times I_{SENSE}) \times \frac{R_G}{1/Gm}$$

$$\text{and } V_{OUT\_CALC} = \frac{[R_{SENSE}\,(1+\text{Tolerance}) \times I_{SENSE} + V_{OFFSET}] \times R_G\,(1+\text{Tolerance})}{1/[Gm\,(1 + Gm\_Accuracy)]}$$

**Figure 11. System Error Equation Assuming $R_{SENSE}$ and $R_G$ are Non-ideal**

Continuing from the previous system error equation, we can recalculate for the system error assuming that $R_G$ has a 1% tolerance.

$$V_{OUT\_THEO} = (100\ m\Omega\ \times 1A) \times \frac{10\ k\Omega}{1/(200\mu)} = 0.2V$$

$$V_{OUT\_CALC} = \frac{[100\ m\Omega\ (1+1/100) \times 1A + 1mV] \times 10\ k\Omega\ (1+1/100)}{1/[200\mu\ (1 + 2/100)]} = 0.21016V$$

$$\text{System Error} = \left|\frac{0.2V - 0.21016V}{0.2V}\right| \times 100 = 5.08\%$$

**Figure 12. System Error Example Assuming $R_{SENSE}$ and $R_G$ are Non-ideal**

Because an $R_G$ tolerance will increase the system error, we recommend selecting an $R_G$ resistor with low tolerance.

### *APPLICATION #1: CURRENT LIMITER WITH A CAPACITIVE LOAD*

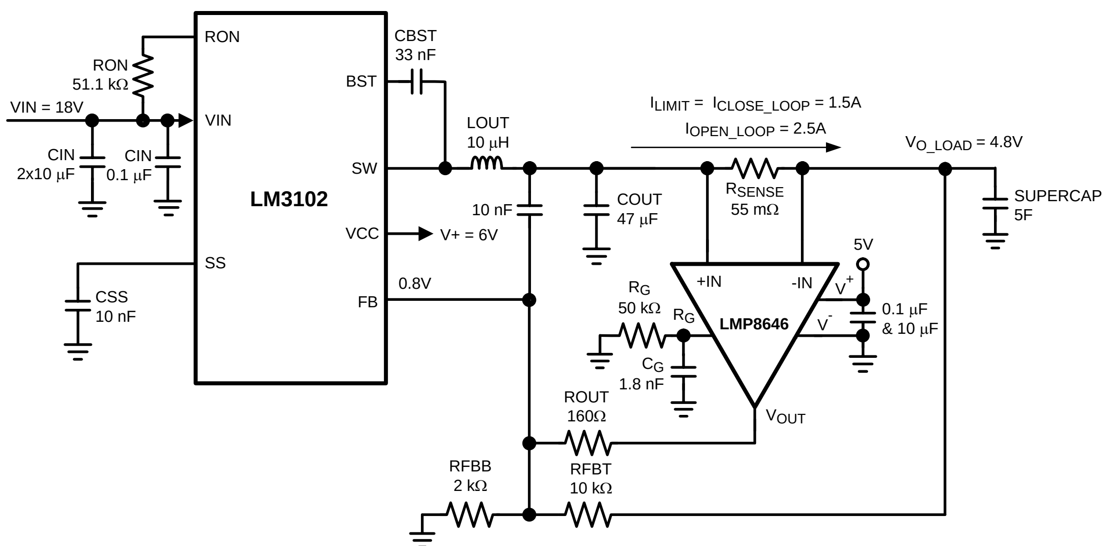



**Figure 13. SuperCap Application with LM3102 Regulator**

A supercap application requires a very high capacitive load to be charged. This example assumes the output capacitor is 5F with a limited sense current at 1.5A. The LM3102 will provide the current to charge the supercap, and the LMP8646 will monitor this current to make sure it does not exceed the desired 1.5A value.

This is done by connecting the LMP8646 output to the feedback pin of the LM3102, as shown in Figure 13. This feedback voltage at the FB pin is compared to a 0.8V internal reference. Any voltage above this 0.8V means the output current is above the desired value of 1.5A, and the LM3102 will reduce its output current to maintain the desired 0.8V at the FB pin.

The following steps show the design procedures for this supercap application. In summary, the steps consist of selecting the components for the voltage regulator, integrating the LMP8646 and selecting the proper values for its gain, bandwidth, and output resistor, and adjusting these components to yield the desired performance.

#### Step 1: Choose the components for the Regulator.

Refer to the LM3102 evaluation board application note (AN-1646) to select the appropriate components for the LM3102 voltage regulator.

#### Step 2: Choose the sense resistor, $R_{SENSE}$

$R_{SENSE}$ sets the voltage $V_{SENSE}$ between +IN and -IN and has the following equation:

$$R_{SENSE} = V_{OUT} / [(I_{LIMIT}) * (R_G / 5kOhm)] \quad (8)$$

In general, $R_{SENSE}$ depends on the output voltage, limit current, and gain. Refer to section SELECTION OF THE SENSE RESISTOR, $R_{SENSE}$ to choose the appropriate $R_{SENSE}$ value; this example uses 55 mOhm.

### Step 3: Choose the gain resistor, $R_G$, for LMP8646

$R_G$ is chosen from the limited sense current. As stated, $V_{OUT} = (R_{SENSE} * I_{LIMIT}) * (R_G / 5kOhm)$. Since $V_{OUT} = V_{FB}$ = 0.8V, the limited sense current is 1.5A, and $R_{SENSE}$ is 55 mOhm, $R_G$ can be calculated as:

$$R_G = (V_{OUT} * 5\ kOhm) / (R_{SENSE} * I_{LIMIT}) \quad (9)$$

$$R_G = (0.8 * 5\ kOhm) / (55\ mOhm * 1.5A) = 50\ kOhm\ (approximate) \quad (10)$$

### Step 4: Choose the Bandwidth Capacitance, $C_G$.

The product of $C_G$ and $R_G$ determines the bandwidth for the LMP8646. Refer to the Typical Performance Characteristics plots to see the range for the LMP8646 bandwidth and gain. Since each application is very unique, the LMP8646 bandwidth capacitance, $C_G$, needs to be adjusted to fit the appropriate application.

Bench data has been collected for the supercap application with the LM3102 regulator, and we found that this application works best for a bandwidth of 500 Hz to 3 kHz. Operating outside of this recommended bandwidth range might create an undesirable load current ringing. We recommend choosing a bandwidth that is in the middle of this range and using the equation $C_G = 1/(2*pi*R_G*Bandwidth)$ to find $C_G$. For example, if the bandwidth is 1.75 kHz and $R_G$ is 50 kOhm, then $C_G$ is approximately 1.8 nF. After this selection, capture the plot for $I_{LIMIT}$ and adjust $C_G$ until a desired load current plot is obtained.

### Step 5: Calculate the Output Accuracy and Tolerable System Error

Since the LMP8646 is a precision current limiter, the output current accuracy is extremely important. This accuracy is affected by the system error contributed by the LMP8646 device error and other errors contributed by external resistances, such as $R_{SENSE}$ and $R_G$.

In this application, $V_{SENSE} = I_{LIMIT} * R_{SENSE}$ = 1.5A * 55 mOhm = 0.0825V, and $R_G$ = 50 kOhm. From the Electrical Characteristics Table, it is known that $V_{OFFSET}$ = 1 mV and Gm_Accuracy = 2%. Using the equations shown in Figure 3, the output accuracy can be calculated as 3.24%.

After figuring out the LMP8646 output accuracy, choose a tolerable system error or the output current accuracy that is bigger than the LMP8646 output accuracy. This tolerable system error will be labeled as $I_{ERROR}$, and it has the equation $I_{ERROR} = (I_{MAX} - I_{LIMIT})/I_{MAX}$ (%). In this example, we will choose an $I_{ERROR}$ of 5%, which will be used to calculate for ROUT shown in the next step.

### Step 6: Choose the output resistor, ROUT

At startup, the capacitor is not charged yet and thus the output voltage of the LM3102 is very small. Therefore, at startup, the output current is at its maximum ($I_{MAX}$). When the output voltage is at its nominal, then the output current will settle to the desired limited value. Because a large current error is not desired, ROUT needs to be chosen to stabilize the loop with minimal initial startup current error. Follow the equations and example below to choose the appropriate value for ROUT to minimize this initial error.

As discussed in step 4, the allowable $I_{ERROR}$ is 5%, where $I_{ERROR} = (I_{MAX} - I_{LIMIT})/I_{MAX}$ (%). Therefore, the maximum allowable current is calculated as: $I_{MAX} = I_{LIMIT} (1+ I_{ERROR})$ = 1.5A * (1 + 5/100) = 1.575 A.

Next, use the formula below to calculate for ROUT:

$$ROUT = \frac{(I_{MAX} * R_{SENSE} * Gain - V_{FB})}{\frac{V_{FB}}{RFBB} - \frac{(V_{O\_REG\_MIN} - V_{FB})}{RFBT}}$$

**Figure 14. ROUT Equation**

For example, assume the minimum LM3102 output voltage, $V_{O\_REG\_MIN}$, is 0.6V, then ROUT can be calculated as ROUT = [1.575A * 55 mOhm * (49.9k / 5k) - 0.8] / [ (0.8 / 2k) - (0.6 - 0.8) / 10k] = 153.6 Ohm.

Populate ROUT with a resistor that is as close as possible to 153.6 Ohm (this application uses 160 Ohm). If the limited sense current has a gain error and is not 1.5A at any point in time, then adjust this ROUT value to obtain the desired limit current.

We recommend that the value for ROUT is at least 50 Ohm.

### Step 7: Adjusting Components

Capture the output current and output voltage plots and adjust the components as necessary. The most common components to adjust are $C_G$ to decrease the current ripple and ROUT to get a low current error. An example output current and voltage plot can be seen in Figure 15 .

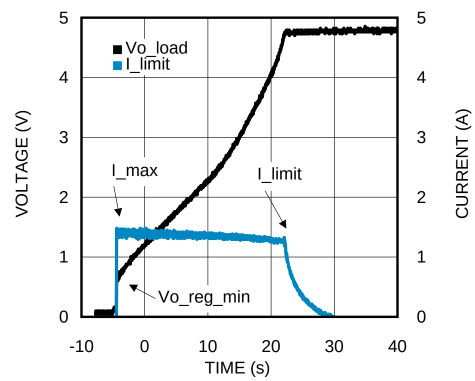



**Figure 15. SuperCap Application with LM3102 Regulator Plot**

## *APPLICATION #2: CURRENT LIMITER WITH A RESISTIVE LOAD*

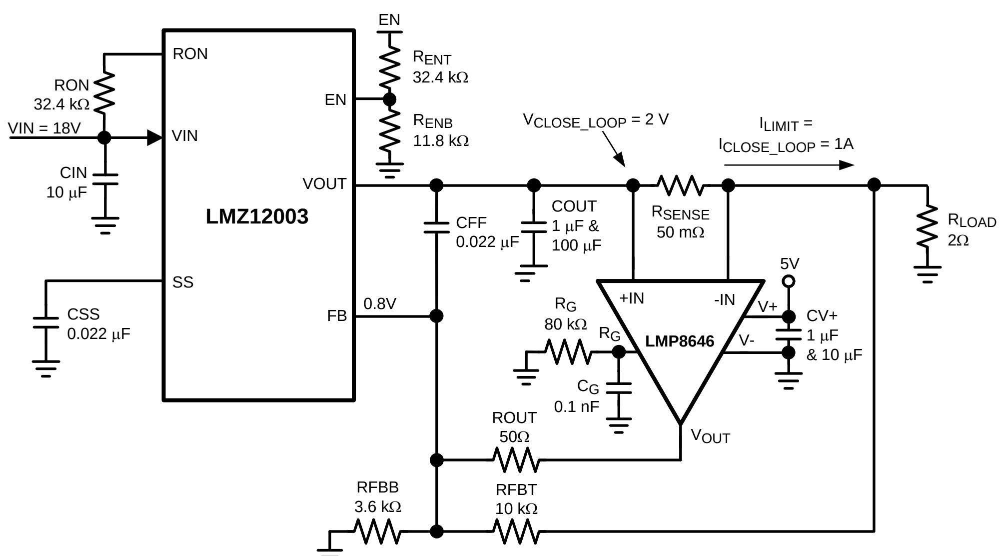



**Figure 16. Resistive Load Application with LMZ12003 Regulator**

This subsection describes the design process for a resistive load application with the LMZ12003 voltage regulator as seen in Figure 16. To see the current limiting capability of the LMP8646, the open-loop current must be greater than the close-loop current. An open-loop occurs when the LMP8646 output is not connected the LMZ12003's feedback pin. For this example, we will let the open-loop current to be 1.5A and the close-loop current, $I_{LIMIT}$, to be 1A.

### Step 1: Choose the components for the Regulator.

Refer to the LMZ12003 application note (AN-2031) to select the appropriate components for the LMZ12003.

### Step 2: Choose the sense resistor, $R_{SENSE}$

$R_{SENSE}$ sets the voltage $V_{SENSE}$ between +IN and -IN and has the following equation:

$$R_{SENSE} = V_{OUT} / [(I_{LIMIT}) * (R_G / 5kOhm)] \quad (11)$$

In general, $R_{SENSE}$ depends on the output voltage, limit current, and gain. Refer to section SELECTION OF THE SENSE RESISTOR, $R_{SENSE}$ to choose the appropriate $R_{SENSE}$ value; this example uses 50 mOhm.

### Step 3: Choose the gain resistor, $R_G$, for LMP8646

$R_G$ is chosen from $I_{LIMIT}$. As stated, $V_{OUT} = (R_{SENSE} * I_{LIMIT}) * (R_G / 5kOhm)$. Since $V_{OUT} = V_{FB} = 0.8V$, $I_{LIMIT} = 1A$, and $R_{SENSE} = 50$ mOhm , $R_G$ can be calculated as:

$$R_G = (V_{OUT} * 5\ kOhm) / (R_{SENSE} * I_{LIMIT}) \quad (12)$$

$$R_G = (0.8 * 5\ kOhm) / (50\ mOhm * 1A) = 80\ kOhm \quad (13)$$

### Step 4: Choose the Bandwidth Capacitance, $C_G$.

The product of $C_G$ and $R_G$ determines the bandwidth for the LMP8646. Refer to the Typical Performance Characteristics plots to see the range for the LMP8646 bandwidth and gain. Since each application is very unique, the LMP8646 bandwidth capacitance, $C_G$, needs to be adjusted to fit the appropriate application.

Bench data has been collected for this resistive load application with the LMZ12003 regulator, and we found that this application works best for a bandwidth of 2 kHz to 30 kHz. Operating anything less than this recommended bandwidth might prevent the LMP8646 from quickly limiting the current. We recommend choosing a bandwidth that is in the middle of this range and using the equation: $C_G = 1/(2*pi*R_G*Bandwidth)$ to find $C_G$ (this example uses a $C_G$ value of 0.1nF). After this selection, capture the load current plot and adjust $C_G$ until a desired output current plot is obtained.

### Step 5: Choose the output resistor, ROUT, for the LMP8646

ROUT plays a very small role in the overall system performance for the resistive load application. ROUT was important in the supercap application because it affects the initial current error. Because current is directly proportional to voltage for a resistive load, the output current is not large at startup. The bigger the ROUT, the longer it takes for the output voltage to reach its final value. We recommend that the value for ROUT is at least 50 Ohm, which is the chosen value for this example.

### Step 6: Adjusting Components

Capture the output current and output voltage plots and adjust the components as necessary. The most common component to adjust is $C_G$ for the bandwidth. An example of the output current and voltage plot can be seen in Figure 17.

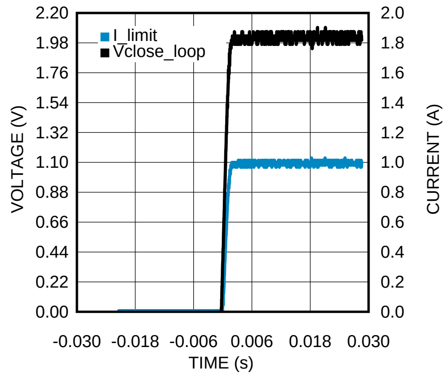



**Figure 17. Plot for the Resistive Load Application with LMZ12003 Regulator Plot**

### APPLICATION #3: CURRENT LIMITER WITH A LOW-DROPOUT REGULATOR AND RESISTIVE LOAD

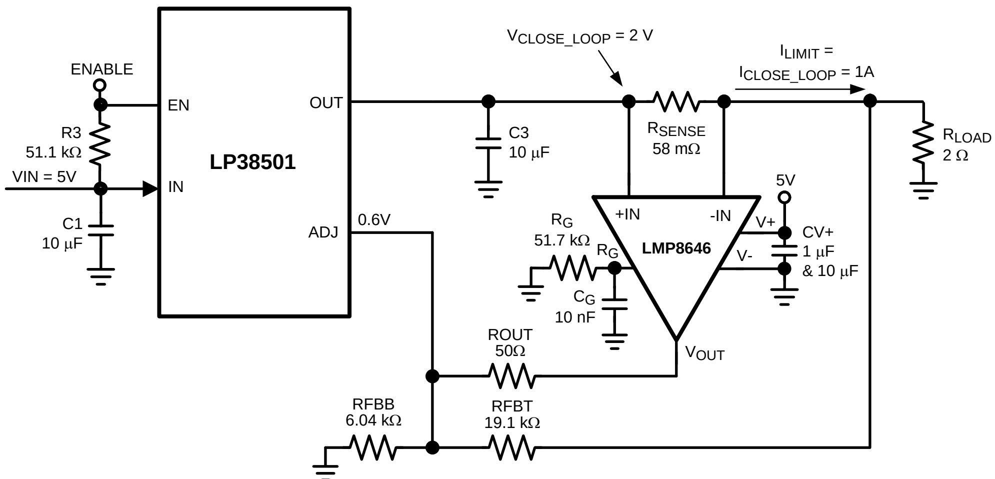



**Figure 18. Resistive Load Application with LP38501 Regulator**

This next example is the same as the last example, except that the regulator is now a low-dropout regulator, the LP38501, as seen in Figure 18. For this example, we will let the open-loop current to be 1.25A and the close-loop current, $I_{LIMIT}$, to be 1A.

#### Step 1: Choose the components for the Regulator.

Refer to the LP38501 application note (AN-1830) to select the appropriate components for the LP38501.

#### Step 2: Choose the sense resistor, $R_{SENSE}$

$R_{SENSE}$ sets the voltage $V_{SENSE}$ between +IN and -IN and has the following equation:

$$R_{SENSE} = V_{OUT} / [(I_{LIMIT}) * (R_G / 5kOhm)] \quad (14)$$

In general, $R_{SENSE}$ depends on the output voltage, limit current, and gain. Refer to section SELECTION OF THE SENSE RESISTOR, $R_{SENSE}$ to choose the appropriate $R_{SENSE}$ value; this example uses 58 mOhm.

### Step 3: Choose the gain resistor, $R_G$, for LMP8646

$R_G$ is chosen from $I_{LIMIT}$. As stated, $V_{OUT}$ = ($R_{SENSE}$ * $I_{LIMIT}$) * ($R_G$ / 5kOhm). Since $V_{OUT}$ = ADJ = 0.6V, $I_{LIMIT}$ = 1A, and $R_{SENSE}$ = 58 mOhm , $R_G$ can be calculated as:

$$R_G = (V_{OUT} * 5\ kOhm) / (R_{SENSE} * I_{LIMIT}) \quad (15)$$

$$R_G = (0.6 * 5\ kOhm) / (58\ mOhm * 1A) = 51.7\ kOhm \quad (16)$$

### Step 4: Choose the Bandwidth Capacitance, $C_G$.

The product of $C_G$ and $R_G$ determines the bandwidth for the LMP8646. Refer to the Typical Performance Characteristics plots to see the range for the LMP8646 bandwidth and gain. Since each application is very unique, the LMP8646 bandwidth capacitance, $C_G$, needs to be adjusted to fit the appropriate application.

Bench data has been collected for this resistive load application with the LP38501 regulator, and we found that this application works best for a bandwidth of 50 Hz to 300 Hz. Operating anything larger than this recommended bandwidth might prevent the LMP8646 from quickly limiting the current. We recommend choosing a bandwidth that is in the middle of this range and using the equation: $C_G$ = 1/(2*pi*$R_G$*Bandwidth) to find $C_G$ (this example uses a $C_G$ value of 10 nF). After this selection, capture the plot for $I_{SENSE}$ and adjust $C_G$ until a desired sense current plot is obtained.

### Step 5: Choose the output resistor, ROUT, for the LMP8646

ROUT plays a very small role in the overall system performance for the resistive load application. ROUT was important in the supercap application because it affects the initial current error. Because current is directly proportional to voltage for a resistive load, the output current is not large at startup. The bigger the ROUT, the longer it takes for the output voltage to reach its final value. We recommend that the value for ROUT is at least 50 Ohm, which is the value we used for this example.

### Step 6: Adjusting Components

Capture the output current and output voltage plots and adjust the components as necessary. The most common component to adjust is $C_G$ for the bandwidth. An example plot of the output current and voltage can be seen in Figure 19.

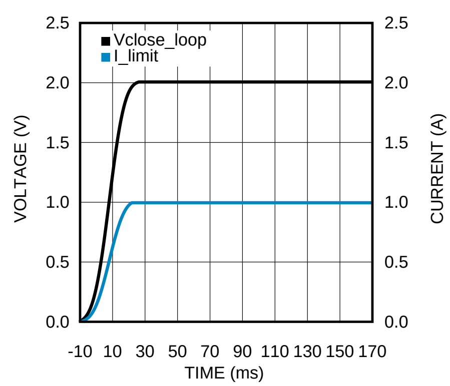



**Figure 19. Plot for the Resistive Load Application with the LP38501 LDO Regulator**

## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish | MSL Peak Temp (3) | Samples (Requires Login) |
|---|---|---|---|---|---|---|---|---|---|
| LMP8646MK/NOPB | ACTIVE | SOT | DDC | 6 | 1000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | |
| LMP8646MKE/NOPB | ACTIVE | SOT | DDC | 6 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | |
| LMP8646MKX/NOPB | ACTIVE | SOT | DDC | 6 | 3000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM | |

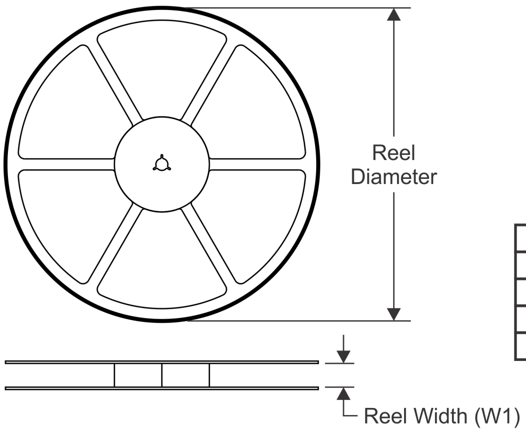
(1) The marketing status values are defined as follows:
**ACTIVE:** Product device recommended for new designs.
**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.
**OBSOLETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
**TBD:** The Pb-Free/Green conversion plan has not been defined.
**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

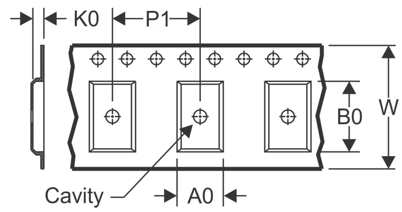
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

## TAPE AND REEL INFORMATION

### REEL DIMENSIONS

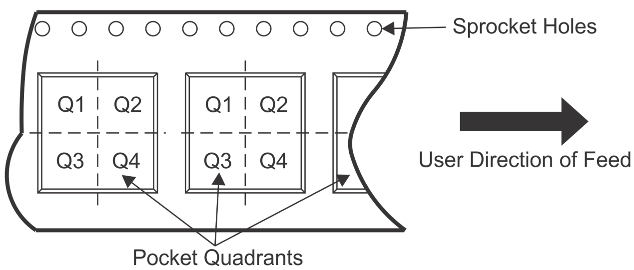



### TAPE DIMENSIONS




| | |
|---|---|
| A0 | Dimension designed to accommodate the component width |
| B0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |

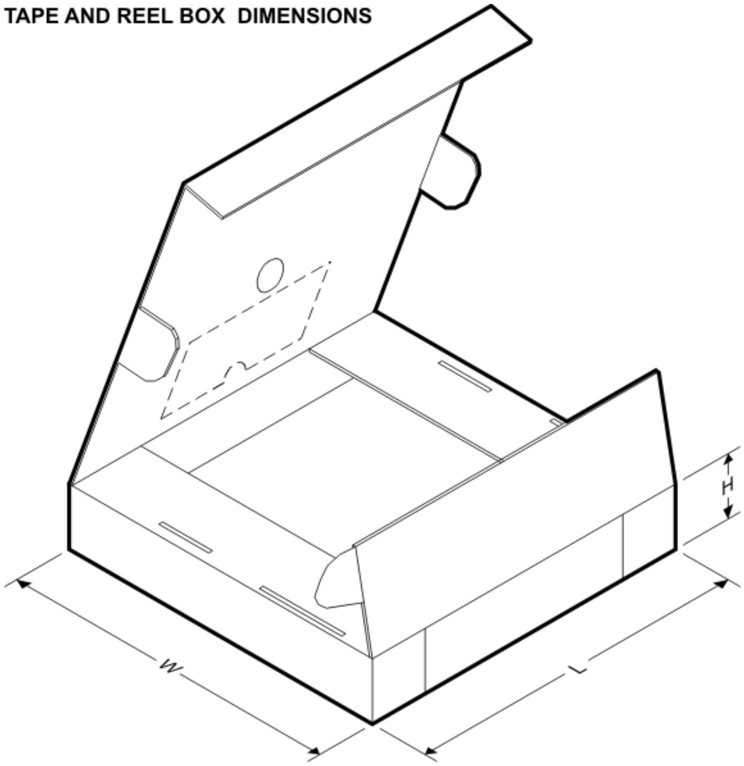
### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE




*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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LMP8646MK/NOPB | SOT | DDC | 6 | 1000 | 178.0 | 8.4 | 3.2 | 3.2 | 1.4 | 4.0 | 8.0 | Q3 |
| LMP8646MKE/NOPB | SOT | DDC | 6 | 250 | 178.0 | 8.4 | 3.2 | 3.2 | 1.4 | 4.0 | 8.0 | Q3 |
| LMP8646MKX/NOPB | SOT | DDC | 6 | 3000 | 178.0 | 8.4 | 3.2 | 3.2 | 1.4 | 4.0 | 8.0 | Q3 |

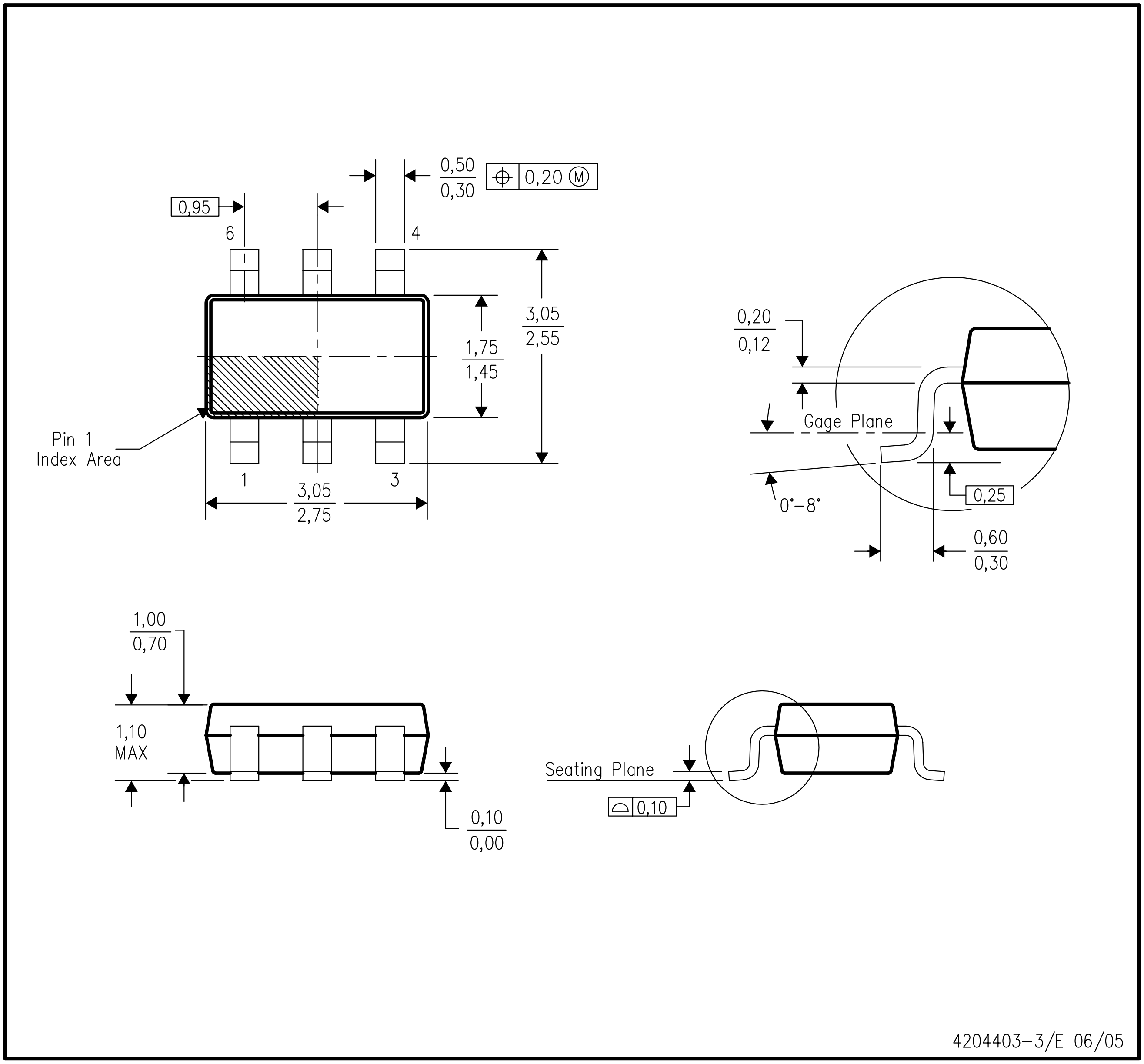
TAPE AND REEL BOX DIMENSIONS




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| LMP8646MK/NOPB | SOT | DDC | 6 | 1000 | 203.0 | 190.0 | 41.0 |
| LMP8646MKE/NOPB | SOT | DDC | 6 | 250 | 203.0 | 190.0 | 41.0 |
| LMP8646MKX/NOPB | SOT | DDC | 6 | 3000 | 206.0 | 191.0 | 90.0 |

DDC (R-PDSO-G6) PLASTIC SMALL-OUTLINE




NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion.
D. Falls within JEDEC MO-193 variation AA (6 pin).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265