# *MAXIM*

# *Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier*

**MAX4173T/F/H**

## General Description

The MAX4173 low-cost, precision, high-side current-sense amplifier is available in a tiny SOT23-6 package. It features a voltage output that eliminates the need for gain-setting resistors and it is ideal for today's notebook computers, cell phones, and other systems where current monitoring is critical. High-side current monitoring is especially useful in battery-powered systems, since it does not interfere with the ground path of the battery charger. The input common-mode range of 0 to +28V is independent of the supply voltage and ensures that the current-sense feedback remains viable even when connected to a battery in deep discharge. The MAX4173's wide 1.7MHz bandwidth makes it suitable for use inside battery charger control loops.

The combination of three gain versions and a user-selectable external sense resistor sets the full-scale current reading. This feature offers a high level of integration, resulting in a simple and compact current-sense solution.

The MAX4173 operates from a single +3V to +28V supply, typically draws only 420µA of supply current over the extended operating temperature range (-40°C to +85°C), and is offered in the space-saving SOT23-6 package.
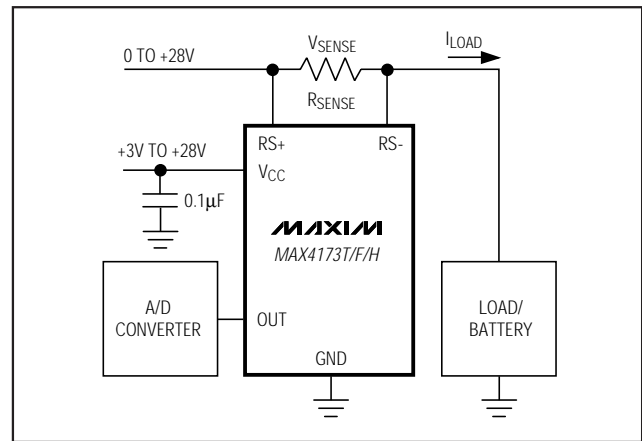
## Applications

Notebook Computers

Portable/Battery-Powered Systems

Smart Battery Packs/Chargers

Cell Phones

Power-Management Systems

General System/Board-Level Current Monitoring

PA Bias Control

Precision Current Sources

## Features

♦ **Low-Cost, Compact Current-Sense Solution**

♦ **Wide 0 to +28V Common-Mode Range Independent of Supply Voltage**

♦ **Three Gain Versions Available**
  **+20V/V (MAX4173T)**
  **+50V/V (MAX4173F)**
  **+100V/V (MAX4173H)**

♦ **±0.5% Full-Scale Accuracy**

♦ **420µA Supply Current**

♦ **Wide 1.7MHz Bandwidth (MAX4173T)**

♦ **+3V to +28V Operating Supply**

♦ **Available in Space-Saving SOT23-6 Package**

## Typical Operating Circuit



## Ordering Information

| PART | GAIN (V/V) | TEMP. RANGE | PIN-PACKAGE | SOT TOP MARK |
|---|---|---|---|---|
| MAX4173TEUT-T | 20 | -40°C to +85°C | 6 SOT23-6 | AABN |
| MAX4173TESA | 20 | -40°C to +85°C | 8 SO | – |
| MAX4173FEUT-T | 50 | -40°C to +85°C | 6 SOT23-6 | AABD |
| MAX4173FESA | 50 | -40°C to +85°C | 8 SO | – |
| MAX4173HEUT-T | 100 | -40°C to +85°C | 6 SOT23-6 | AABP |
| MAX4173HESA | 100 | -40°C to +85°C | 8 SO | – |

*Pin Configurations appear at end of data sheet.*

*MAXIM* _____ *Maxim Integrated Products*   **1**

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*For small orders, phone 1-800-835-8769.*

# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

## ABSOLUTE MAXIMUM RATINGS

$V_{CC}$, RS+, RS- to GND ........................................... -0.3V to +30V
OUT to GND .............................................. -0.3V to ($V_{CC}$ + 0.3V)
Output Short-Circuit to $V_{CC}$ or GND ......................... Continuous
Differential Input Voltage ($V_{RS+}$ - $V_{RS-}$) ............................ ±0.3V
Current into Any Pin ....................................................... ±20mA

Continuous Power Dissipation ($T_A$ = +70°C)
    8-Pin SO (derate 5.88mW/°C above +70°C) ............... 471mW
    SOT23-6 (derate 8.7mW/°C above +70°C) ................. 696mW
Operating Temperature Range ......................... -40°C to +85°C
Storage Temperature Range ........................... -65°C to +150°C
Lead Temperature (soldering, 10sec) ........................... +300°C

*Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

## ELECTRICAL CHARACTERISTICS

($V_{RS+}$ = 0 to +28V, $V_{CC}$ = +3V to +28V, $V_{SENSE}$ = 0, $T_A$ = $T_{MIN}$ to $T_{MAX}$, $R_{LOAD}$ = ∞ unless otherwise noted. Typical values are at $T_A$ = +25°C.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Operating Voltage Range | $V_{CC}$ | Guaranteed by PSR test | 3 | | 28 | V |
| Common-Mode Input Range | $V_{CMR}$ | (Note 2) | 0 | | 28 | V |
| Common-Mode Rejection | CMR | $V_{RS+}$ > +2.0V | | 90 | | dB |
| Supply Current | $I_{CC}$ | $V_{RS+}$ > +2.0V, $V_{CC}$ = 12V | | 0.42 | 1.0 | mA |
| Leakage Current | $I_{RS+}$, $I_{RS-}$ | $V_{CC}$ = 0 | | 0.3 | 3 | µA |
| Input Bias Current | $I_{RS+}$ | $V_{RS+}$ > +2.0V | 0 | | 50 | µA |
| | | $V_{RS+}$ ≤ +2.0V | -350 | | 50 | |
| | $I_{RS-}$ | $V_{RS+}$ > +2.0V | 0 | | 100 | |
| | | $V_{RS+}$ ≤ +2.0V | -700 | | 100 | |
| Full-Scale Sense Voltage | $V_{SENSE}$ | $V_{SENSE}$ = $V_{RS+}$ - $V_{RS-}$ | | 150 | | mV |
| Total OUT Voltage Error (Note 3) | | $V_{SENSE}$ = +100mV, $V_{CC}$ = +12V, $V_{RS+}$ = +12V | | ±0.5 | 5.75 | % |
| | | $V_{SENSE}$ = +100mV, $V_{CC}$ = +12V, $V_{RS+}$ = +12V, $T_A$ = +25°C | | 0.5 | 3.25 | |
| | | $V_{SENSE}$ = +100mV, $V_{CC}$ = +28V, $V_{RS+}$ = +28V | | 0.5 | 5.75 | |
| | | $V_{SENSE}$ = +100mV, $V_{CC}$ = +12V, $V_{RS+}$ = +0.1V | | -9 | ±24 | |
| | | $V_{CC}$ = +12V, $V_{RS+}$ =+12V, $V_{SENSE}$ = +6.25mV (Note 4) | | ±7.5 | | |
| OUT High Voltage (Note 5) | ($V_{CC}$ - $V_{OH}$) | MAX4173T, $V_{CC}$ = +3.0V | | 0.8 | 1.2 | V |
| | | MAX4173F, $V_{CC}$ = +7.5V | | 0.8 | 1.2 | |
| | | MAX4173H, $V_{CC}$ = +15V | | 0.8 | 1.2 | |

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# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

## ELECTRICAL CHARACTERISTICS (continued)

($V_{RS+}$ = 0 to +28V, $V_{CC}$ = +3V to +28V, $V_{SENSE}$ = 0, $T_A$ = $T_{MIN}$ to $T_{MAX}$, $R_{LOAD}$ = ∞ unless otherwise noted. Typical values are at $T_A$ = +25°C.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Bandwidth | BW | $V_{RS+}$ = +12V, $V_{CC}$ = +12V, $C_{LOAD}$ = 5pF | MAX4173T, $V_{SENSE}$ = +100mV, | | 1.7 | | MHz |
| | | | MAX4173F, $V_{SENSE}$ = +100mV, | | 1.4 | | |
| | | | MAX4173H, $V_{SENSE}$ = +100mV, | | 1.2 | | |
| | | | $V_{SENSE}$ = +6.25mV, (Note 4) | | 0.6 | | |
| Gain | $A_V$ | MAX4173T | | | 20 | | V/V |
| | | MAX4173F | | | 50 | | |
| | | MAX4173H | | | 100 | | |
| Gain Accuracy | $\Delta A_V$ | MAX4173T/F $V_{SENSE}$ = +10mV to +150mV | $T_A$ = -40°C to +85°C | | | 4.0 | % |
| | | | $T_A$ = +25°C | | 0.5 | ±2.5 | |
| | | MAX4173H $V_{SENSE}$ = +10mV to +100mV | $T_A$ = -40°C to +85°C | | | 4.0 | |
| | | | $T_A$ = +25°C | | 0.5 | ±2.5 | |
| OUT Settling Time to 1% of Final Value | | $V_{CC}$ = +12V, $V_{RS+}$ = +12V, $C_{LOAD}$ = 5pF | $V_{SENSE}$ = +6.25mV to +100mV | | 400 | | ns |
| | | | $V_{SENSE}$ = +100mV to +6.25mV | | 800 | | |
| OUT Output Resistance | $R_{OUT}$ | | | | 12 | | kΩ |
| Power-Supply Rejection | PSR | MAX4173T, $V_{SENSE}$ = 80mV, $V_{RS+}$ ≥ +2V | | 60 | 84 | | dB |
| | | MAX4173F, $V_{SENSE}$ = 32mV, $V_{RS+}$ ≥ +2V | | 60 | 91 | | |
| | | MAX4173H, $V_{SENSE}$ = 16mV, $V_{RS+}$ ≥ +2V | | 60 | 95 | | |
| Power-Up Time to 1% of Final Value | | $V_{SENSE}$ = +100mV, $C_{LOAD}$ = 5pF | | | 10 | | µs |
| Saturation Recovery Time | | $V_{CC}$ = +12V, $V_{RS+}$ = +12V (Note 6) | | | 10 | | µs |

**Note 1:** All devices are 100% production tested at $T_A$ = +25°C. All temperature limits are guaranteed by design.
**Note 2:** Guaranteed by Total Output Voltage Error Test.
**Note 3:** Total OUT Voltage Error is the sum of gain and offset voltage errors.
**Note 4:** +6.25mV = 1/16 of +100mV full-scale voltage.
**Note 5:** $V_{SENSE}$ such that output stage is in saturation.
**Note 6:** The device does not experience phase reversal when overdriven.
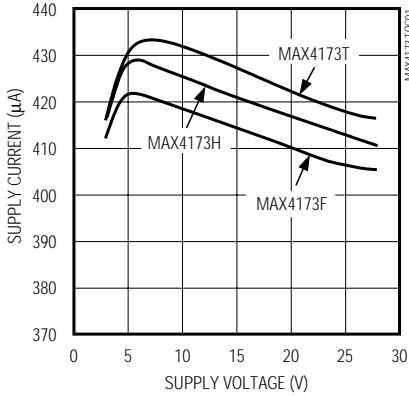
**MAXIM** _____ **3**

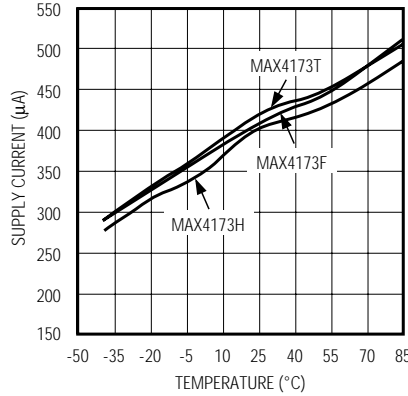# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

*MAX4173T/F/H*

## *Typical Operating Characteristics*

(V_CC = +12V, V_RS+ = +12V, V_SENSE = +100mV, T_A = +25°C, unless otherwise noted.)
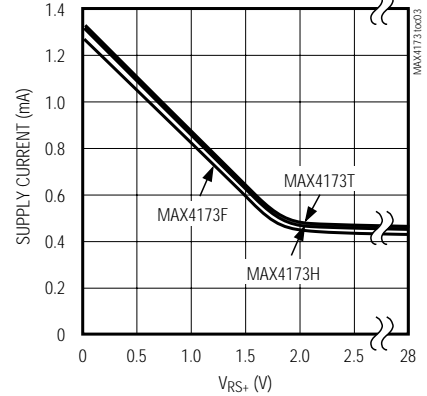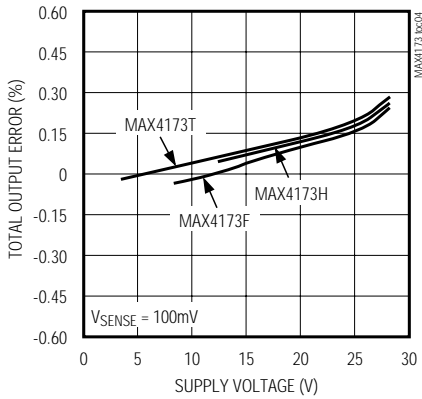


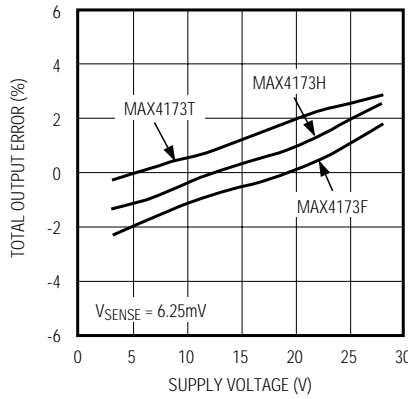SUPPLY CURRENT vs. SUPPLY VOLTAGE



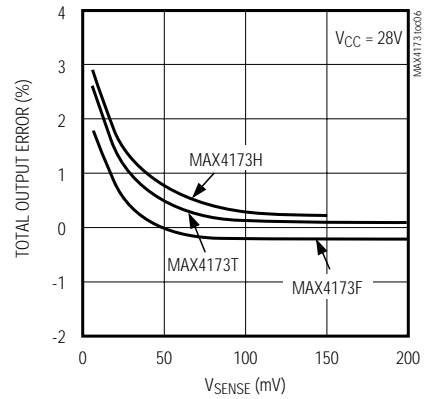SUPPLY CURRENT vs. TEMPERATURE



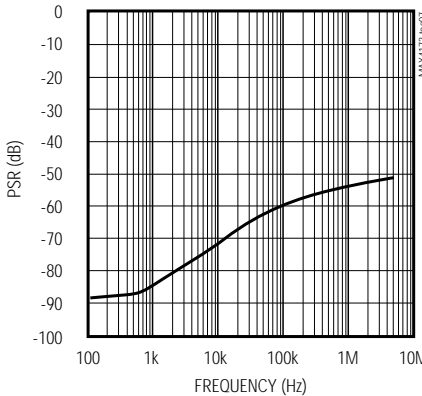SUPPLY CURRENT vs. RS+ VOLTAGE



TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE



TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE
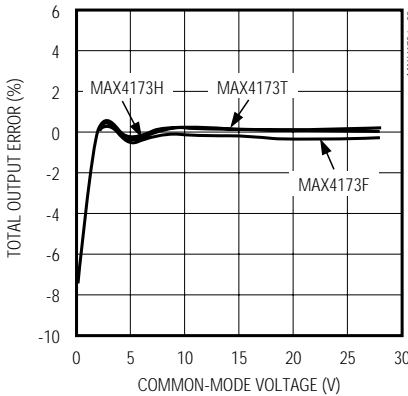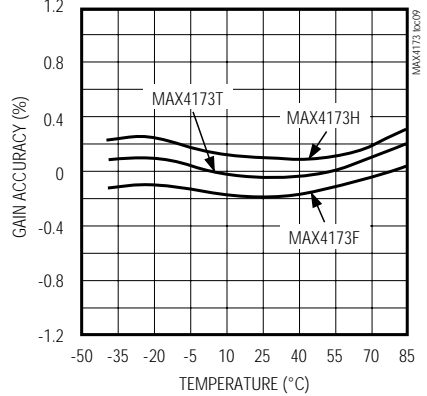


TOTAL OUTPUT ERROR vs. FULL-SCALE SENSE VOLTAGE



POWER-SUPPLY REJECTION vs. FREQUENCY



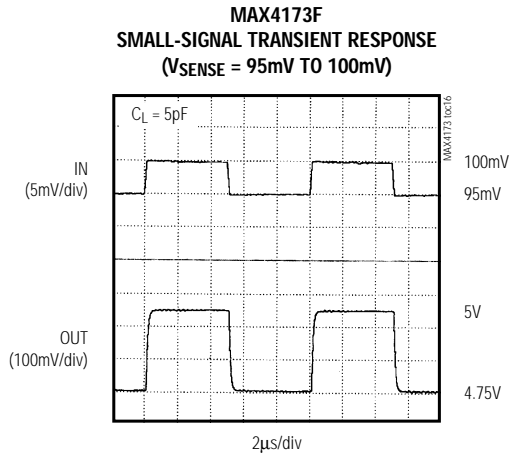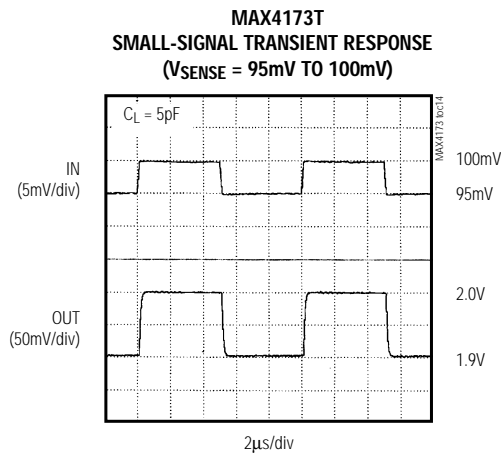TOTAL OUTPUT ERROR vs. COMMON-MODE VOLTAGE



GAIN ACCURACY vs. TEMPERATURE

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# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

## Typical Operating Characteristics (continued)

($V_{CC}$ = +12V, $V_{RS+}$ = +12V, $V_{SENSE}$ = +100mV, $T_A$ = +25°C, unless otherwise noted.)

**TOTAL OUTPUT ERROR vs. TEMPERATURE**

**MAX4173T LARGE-SIGNAL TRANSIENT RESPONSE ($V_{SENSE}$ = 6mV to 100mV)**

**MAX4173F LARGE-SIGNAL TRANSIENT RESPONSE ($V_{SENSE}$ = 6mV to 100mV)**

**MAX4173H LARGE-SIGNAL TRANSIENT RESPONSE ($V_{SENSE}$ = 6mV to 100mV)**

**MAX4173T SMALL-SIGNAL TRANSIENT RESPONSE ($V_{SENSE}$ = 95mV TO 100mV)**

**MAX4173F SMALL-SIGNAL TRANSIENT RESPONSE ($V_{SENSE}$ = 95mV TO 100mV)**
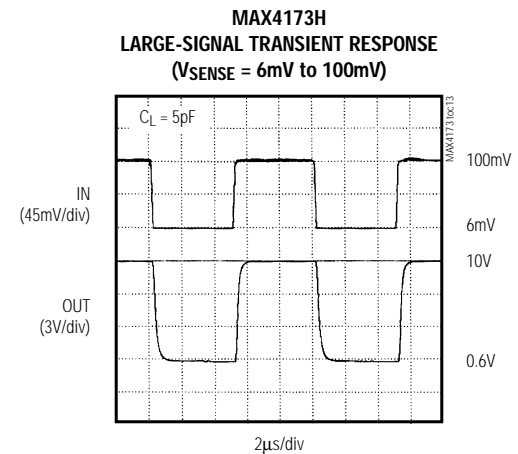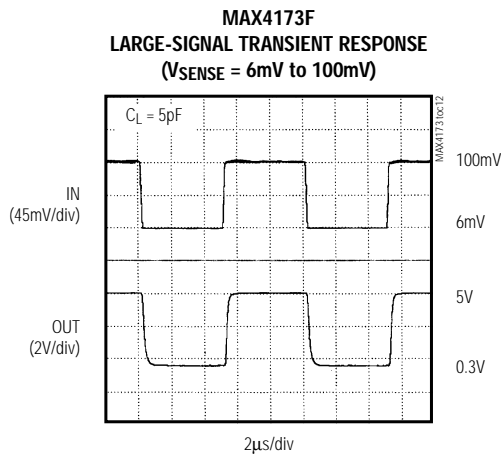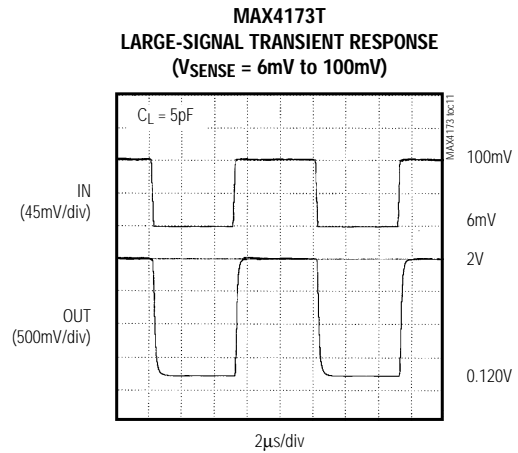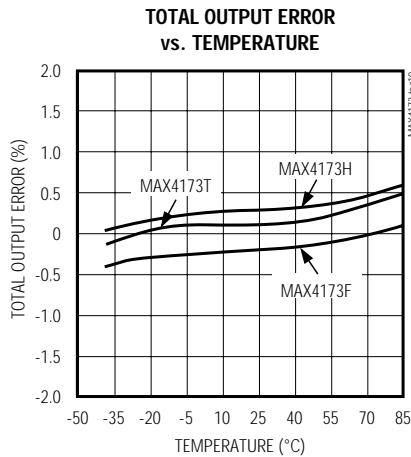
*MAX4173T/F/H*

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# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

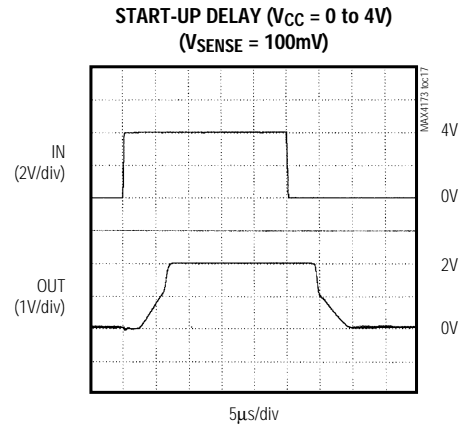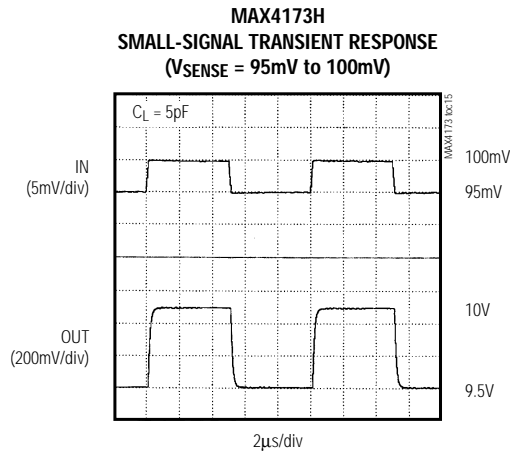**MAX4173T/F/H**

## Typical Operating Characteristics (continued)

($V_{CC}$ = +12V, $V_{RS+}$ = +12V, $V_{SENSE}$ = +100mV, $T_A$ = +25°C, unless otherwise noted.)

**MAX4173H**
**SMALL-SIGNAL TRANSIENT RESPONSE**
**($V_{SENSE}$ = 95mV to 100mV)**



**START-UP DELAY ($V_{CC}$ = 0 to 4V)**
**($V_{SENSE}$ = 100mV)**



## Pin Description

| PIN | | NAME | FUNCTION |
|---|---|---|---|
| **SOT23-6** | **SO** | | |
| 1, 2 | 3 | GND | Ground |
| 3 | 1 | $V_{CC}$ | Supply Voltage Input. Bypass to GND with a 0.1µF capacitor. |
| 4 | 8 | RS+ | Power-Side Connection to the External Sense Resistor |
| 5 | 6 | RS- | Load-Side Connection for the External Sense Resistor |
| 6 | 4 | OUT | Voltage Output. $V_{OUT}$ is proportional to $V_{SENSE}$ ( $V_{RS+}$ - $V_{RS-}$ ). Output impedance is approximately 12kΩ. |
| – | 2, 5, 7 | N.C. | No Connection. Not internally connected. |

# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

**MAX4173T/F/H**

## Detailed Description

The MAX4173 high-side current-sense amplifier features a 0 to +28V input common-mode range that is independent of supply voltage. This feature allows the monitoring of current out of a battery in deep discharge and also enables high-side current sensing at voltages greater than the supply voltage ($V_{CC}$).

The MAX4173 operates as follows: Current from the source flows through $R_{SENSE}$ to the load (Figure 1). Since the internal-sense amplifier's inverting input has high impedance, negligible current flows through RG2 (neglecting the input bias current). Therefore, the sense amplifier's inverting-input voltage equals $V_{SOURCE}$ - ($I_{LOAD}$)($R_{SENSE}$). The amplifier's open-loop gain forces its noninverting input to the same voltage as the inverting input. Therefore, the drop across RG1 equals ($I_{LOAD}$)($R_{SENSE}$). Since $I_{RG1}$ flows through RG1, $I_{RG1}$ = ($I_{LOAD}$)($R_{SENSE}$) / RG1. The internal current mirror multiplies $I_{RG1}$ by a current gain factor, $\beta$, to give $I_{RGD}$ = $\beta \cdot I_{RG1}$. Solving $I_{RGD}$ = $\beta \cdot$ ($I_{LOAD}$)($R_{SENSE}$) / RG1. Assuming infinite output impedance, $V_{OUT}$ = ($I_{RGD}$)(RGD). Substituting in for $I_{RGD}$ and rearranging, $V_{OUT}$ = $\beta \cdot$ (RGD / RG1)($R_{SENSE} \cdot I_{LOAD}$). The parts gain equals $\beta \cdot$ RGD / RG1. Therefore, $V_{OUT}$ = (GAIN) ($R_{SENSE}$)($I_{LOAD}$), where GAIN = 20 for MAX4173T, GAIN = 50 for MAX4173F, and GAIN = 100 for MAX4173H.



Figure 1. Functional Diagram

Set the full-scale output range by selecting $R_{SENSE}$ and the appropriate gain version of the MAX4173.

## Applications Information

### Recommended Component Values

The MAX4173 senses a wide variety of currents with different sense resistor values. Table 1 lists common resistor values for typical operation of the MAX4173.

### Choosing $R_{SENSE}$

To measure lower currents more accurately, use a high value for $R_{SENSE}$. The high value develops a higher sense voltage that reduces offset voltage errors of the internal op amp.

In applications monitoring very high currents, $R_{SENSE}$ must be able to dissipate the $I^2R$ losses. If the resistor's rated power dissipation is exceeded, its value may drift or it may fail altogether, causing a differential voltage across the terminals in excess of the absolute maximum ratings.

If $I_{SENSE}$ has a large high-frequency component, minimize the inductance of $R_{SENSE}$. Wire-wound resistors have the highest inductance, metal-film resistors are somewhat better, and low-inductance metal-film resistors are best suited for these applications.

### Using a PCB Trace as $R_{SENSE}$

If the cost of $R_{SENSE}$ is an issue and accuracy is not critical, use the alternative solution shown in Figure 2. This solution uses copper PC board traces to create a sense resistor. The resistivity of a 0.1-inch-wide trace of 2-ounce copper is approximately 30m$\Omega$/ft. The resistance-temperature coefficient of copper is fairly high (approximately 0.4%/°C), so systems that experience a wide temperature variance must compensate for this effect. In addition, do not exceed the maximum power dissipation of the copper trace.

For example, the MAX4173T (with a maximum load current of 10A and an $R_{SENSE}$ of 5m$\Omega$) creates a full-scale $V_{SENSE}$ of 50mV that yields a maximum $V_{OUT}$ of 1V. $R_{SENSE}$ in this case requires about 2 inches of 0.1 inch-wide copper trace.

### Output Impedance

The output of the MAX4173 is a current source driving a 12k$\Omega$ resistance. Resistive loading added to OUT reduces the output gain of the MAX4173. To minimize output errors for most applications, connect OUT to a high-impedance input stage. When output buffering is required, choose an op amp with a common-mode input range and an output voltage swing that includes ground when operating with a single supply. The op
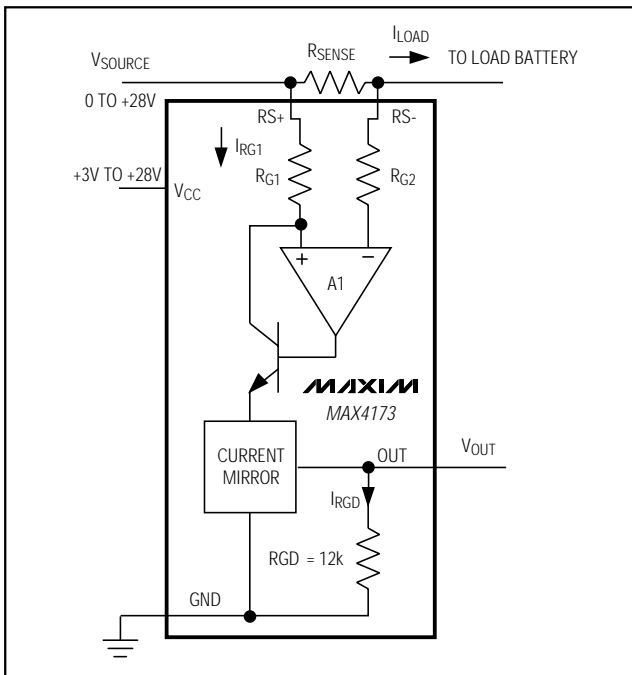
**MAXIM** _____ 7

# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

**MAX4173T/F/H**

## Table 1. Recommended Component Values

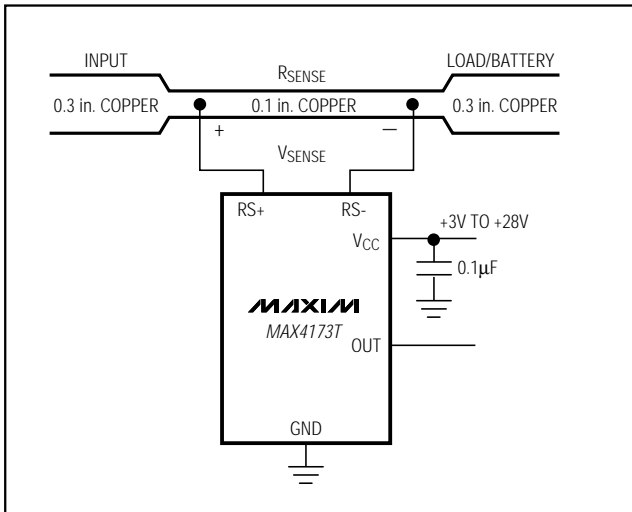| FULL-SCALE LOAD CURRENT $I_{LOAD}$ (A) | CURRENT-SENSE RESISTOR $R_{SENSE}$ (m$\Omega$) | GAIN | FULL-SCALE OUTPUT VOLTAGE (FULL-SCALE $V_{SENSE}$ = 100mV) $V_{OUT}$ (V) |
|---|---|---|---|
| 0.1 | 1000 | 20 | 2.0 |
|  |  | 50 | 5.0 |
|  |  | 100 | 10.0 |
| 1 | 100 | 20 | 2.0 |
|  |  | 50 | 5.0 |
|  |  | 100 | 10.0 |
| 5 | 20 | 20 | 2.0 |
|  |  | 50 | 5.0 |
|  |  | 100 | 10.0 |
| 10 | 10 | 20 | 2.0 |
|  |  | 50 | 5.0 |
|  |  | 100 | 10.0 |



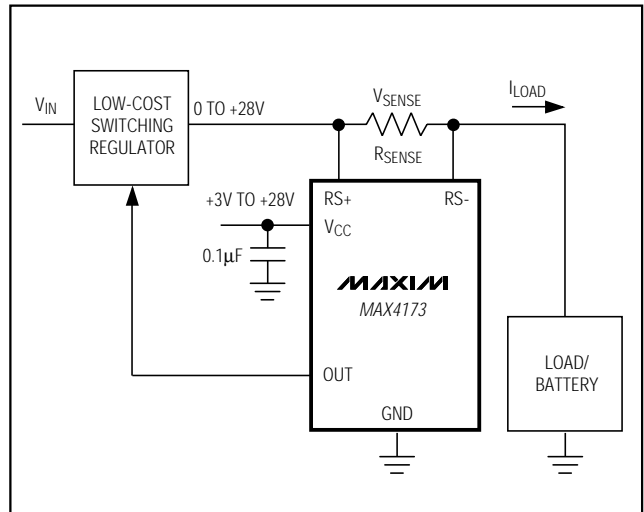Figure 2. MAX4173 Connections Showing Use of PC Board



Figure 3. Current Source

amp's supply voltage range should be at least as high as any voltage the system may encounter.

The percent error introduced by output loading is determined with the following formula:

$$\%_{ERROR} = 100\left(\frac{R_{LOAD}}{12k\Omega + R_{LOAD}} - 1\right)$$

where $R_{LOAD}$ is the external load applied to OUT.

### Current Source Circuit

Figure 3 shows a block diagram using the MAX4173 with a switching regulator to make a current source.

**MAXIM**

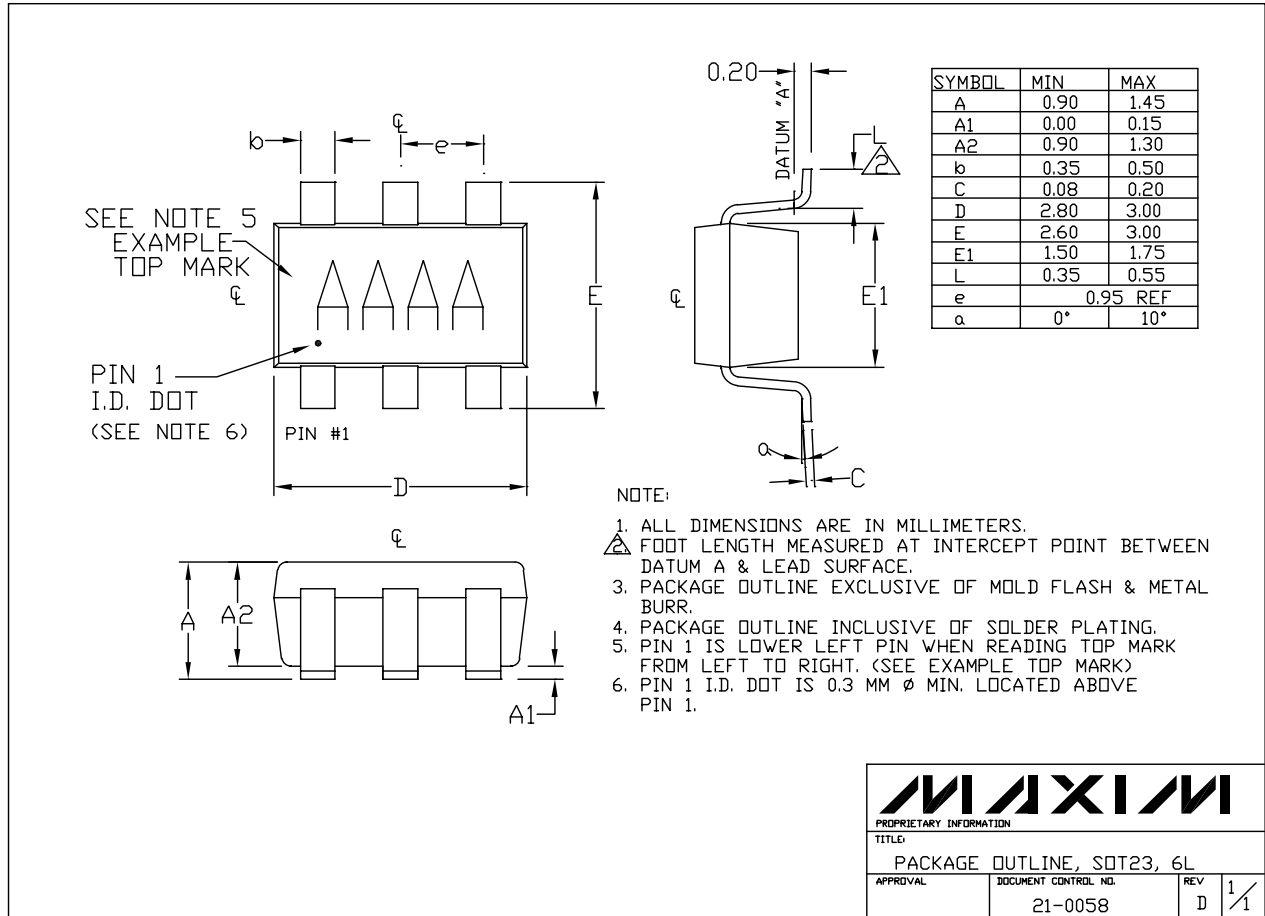# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

*Pin Configurations*

TOP VIEW



SOT23-6



SO

*Chip Information*

TRANSISTOR COUNT: 187

MAX4173T/F/H

# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

**MAX4173T/F/H**

## Package Information

6LSOT.EPS



| SYMBOL | MIN | MAX |
|--------|------|------|
| A | 0.90 | 1.45 |
| A1 | 0.00 | 0.15 |
| A2 | 0.90 | 1.30 |
| b | 0.35 | 0.50 |
| C | 0.08 | 0.20 |
| D | 2.80 | 3.00 |
| E | 2.60 | 3.00 |
| E1 | 1.50 | 1.75 |
| L | 0.35 | 0.55 |
| e | 0.95 REF | |
| α | 0° | 10° |

NOTE:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. FOOT LENGTH MEASURED AT INTERCEPT POINT BETWEEN DATUM A & LEAD SURFACE.
3. PACKAGE OUTLINE EXCLUSIVE OF MOLD FLASH & METAL BURR.
4. PACKAGE OUTLINE INCLUSIVE OF SOLDER PLATING.
5. PIN 1 IS LOWER LEFT PIN WHEN READING TOP MARK FROM LEFT TO RIGHT. (SEE EXAMPLE TOP MARK)
6. PIN 1 I.D. DOT IS 0.3 MM Ø MIN. LOCATED ABOVE PIN 1.

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PROPRIETARY INFORMATION
TITLE:
PACKAGE OUTLINE, SOT23, 6L
APPROVAL | DOCUMENT CONTROL NO. | REV | 1/1
| 21-0058 | D |

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# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

**Package Information (continued)**

SOICN.EPS



| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 0.053 | 0.069 | 1.35 | 1.75 |
| A1 | 0.004 | 0.010 | 0.10 | 0.25 |
| B | 0.014 | 0.019 | 0.35 | 0.49 |
| C | 0.007 | 0.010 | 0.19 | 0.25 |
| e | 0.050 | | 1.27 | |
| E | 0.150 | 0.157 | 3.80 | 4.00 |
| H | 0.228 | 0.244 | 5.80 | 6.20 |
| h | 0.010 | 0.020 | 0.25 | 0.50 |
| L | 0.016 | 0.050 | 0.40 | 1.27 |

| | INCHES | | MILLIMETERS | | N | MS012 |
|---|---|---|---|---|---|---|
| | MIN | MAX | MIN | MAX | | |
| D | 0.189 | 0.197 | 4.80 | 5.00 | 8 | A |
| D | 0.337 | 0.344 | 8.55 | 8.75 | 14 | B |
| D | 0.386 | 0.394 | 9.80 | 10.00 | 16 | C |

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. LEADS TO BE COPLANAR WITHIN .102mm (.004")
4. CONTROLLING DIMENSION: MILLIMETER
5. MEETS JEDEC MS012-XX AS SHOWN IN ABOVE TABLE
6. N = NUMBER OF PINS

**MAXIM**
120 SAN GABRIEL DR  SUNNYVALE CA 94086  FAX (408) 737 7194
PROPRIETARY INFORMATION

PACKAGE FAMILY OUTLINE: SOIC .150"
TITLE

1/1

21-0041 A
DOCUMENT CONTROL NUMBER    REV

MAX4173T/F/H

**MAXIM**

11

# Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

**MAX4173T/F/H**

## NOTES

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　　　　西安劳动南路 88 号电子商城二楼 D23 号
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