Keywords: Current Sense amp, Current sense amplifer, bidirectional, unidirectional, charge, discharge Aug 21, 2006

APPLICATION NOTE 3906

Creating a Bidirectional Current-Sense Amplifier from Two Unidirectional Current-Sense Amplifiers

In many battery-current monitoring applications, bidirectional current sensing is required to measure both charge and discharge currents in the battery. This application note describes how to connect two unidirectional current-output, current-sense amps, such as the MAX4172 and MAX4173, to form one bidirectional current-sense amplifier.

Introduction

Many current-sense applications require bidirectional current-sensing capabilities. For instance, when a laptop is plugged into an AC power line, the AC adapter supplies power to the laptop and charges the battery. The battery's charge current is monitored to ensure that the battery does not overheat and that the total input power drawn from the AC adapter does not exceed UL-mandated limits. Similarly, the battery discharge current is monitored for fuel-gauging/active power management on the load device when the AC adapter is not available and battery capacity needs to be conserved. **Figure 1** shows a typical current-sense amplifier implementation in a battery-charging/-discharging application.

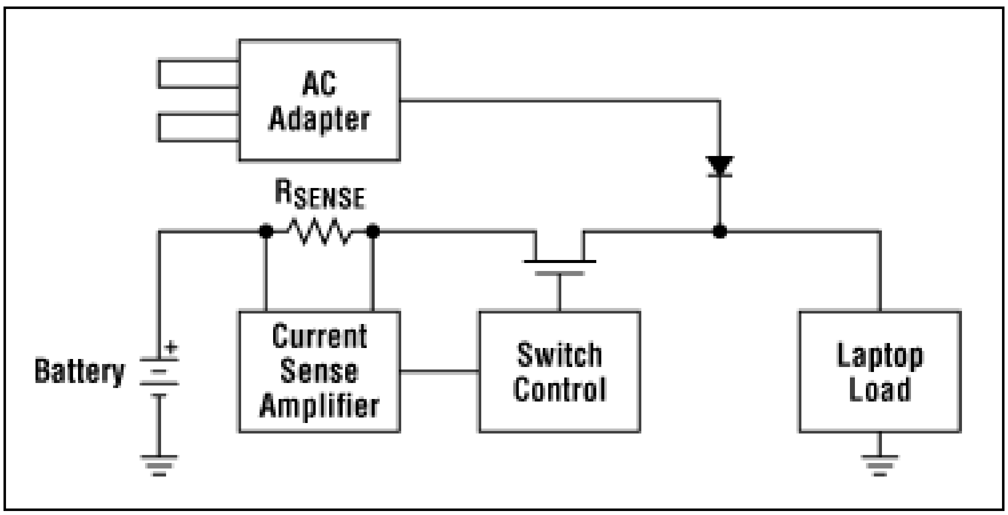

Figure 1. The typical battery-charging/-discharging circuit used in laptop applications.

Building a Bidirectional Current-Sense Amplifier

The MAX4172, MAX4173, and MAX4073 are three popular unidirectional current-sense amplifiers that feature current outputs. The MAX4172 is available in a µMAX® package and offers precision 1.6mV maximum offset voltage (0.75mV V_{OS} for SOIC version) and ±2% maximum gain-error specifications over the industrial temperature range. The MAX4173 is available in a tiny SOT23 package; it features 3mV maximum offset and an internal 12kΩ load resistor to convert its current output to a voltage output. The MAX4073 is similarly available in a tiny SC70 package. All three devices also have high signal bandwidths, making them attractive solutions within analog control loops.

The voltage-input, current-output feature of these devices enables one to leverage them in a wide variety of clever circuits. One can, for example, use two unidirectional current-sense amplifiers—such as MAX4172 or MAX4173—to build a fast bidirectional current-sense amplifier (**Figure 2**).

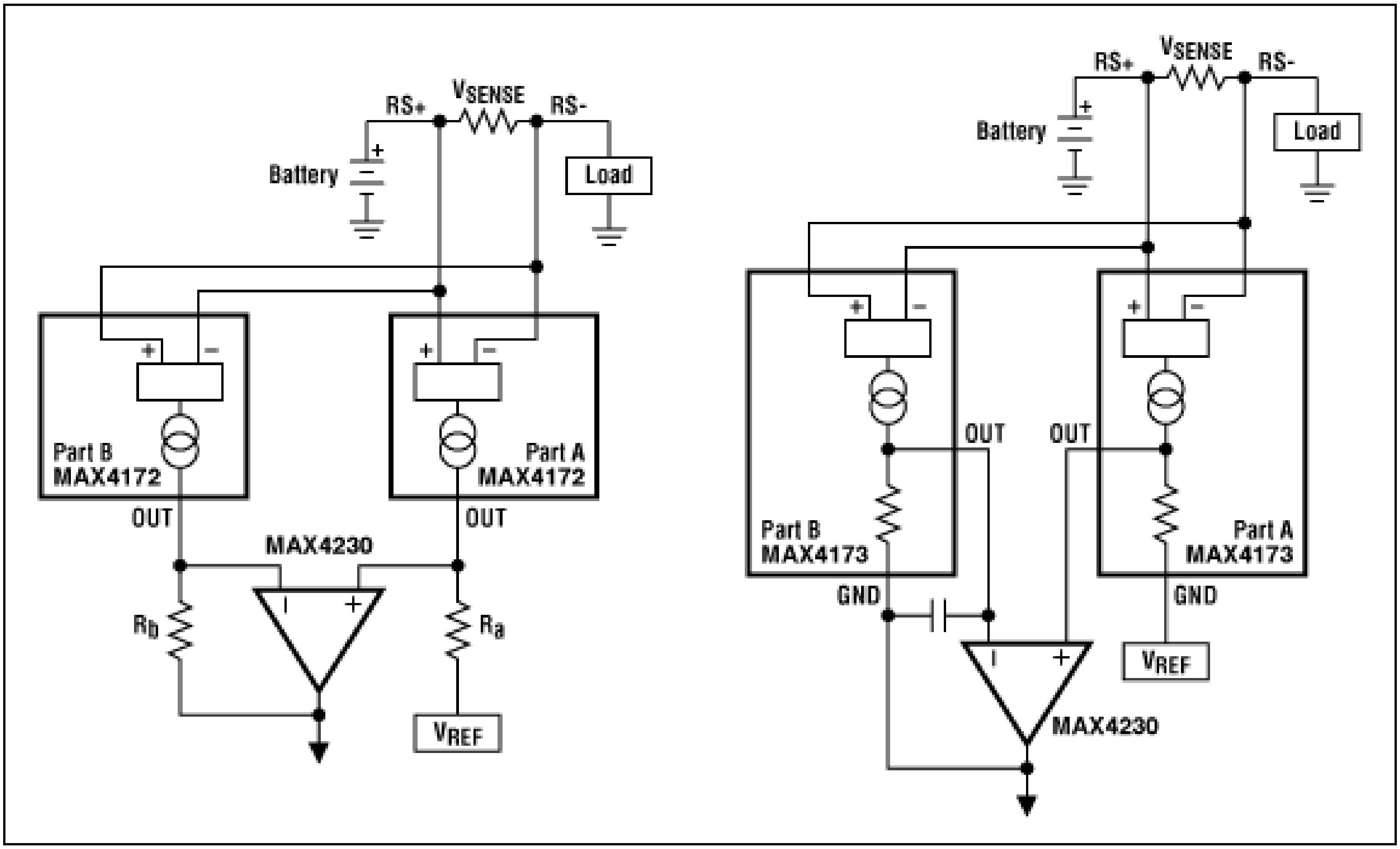

Figure 2. Two circuits showing bidirectional current-sense applications created from two unidirectional current-sense amplifiers.

Part A is active when $V_{RS+} > V_{RS-}$ (i.e., when the battery is supplying the load current) and Part B is active when $V_{RS-} > V_{RS+}$ (i.e., when the battery is being charged by the AC adapter). A general purpose op-amp combines the output currents from the two amplifiers into an appropriate output voltage. V_{REF} sets the output voltage at zero current (zero-sense voltage). The output voltage increases above V_{REF} when Part A is active and decreases below V_{REF} when Part B is active. By using $R_a \neq R_b$ in the MAX4172 circuit, different gains can be used for positive (discharging) currents and negative (charging) currents.

The MAX4173 circuit uses a 1nF capacitor in its feedback to stabilize the control loop. Since the GND pin of Part B is modulated by the output of the op-amp, the V_{CC} applied to the MAX4173 should be at least 3V above the maximum output of MAX4230. This value ensures sufficient supply-voltage headroom for proper operation of the device).

Transfer characteristics for both MAX4172 and MAX4173 circuits are provided in **Figure 3** and **Figure 4**, respectively.

Conditions for MAX4172 circuit are:

V_{BAT} = 8V
V_{CC} = 3.3V for MAX4172 and MAX4230
Ra = Rb = 1kΩ

V_{REF} = 1.2V

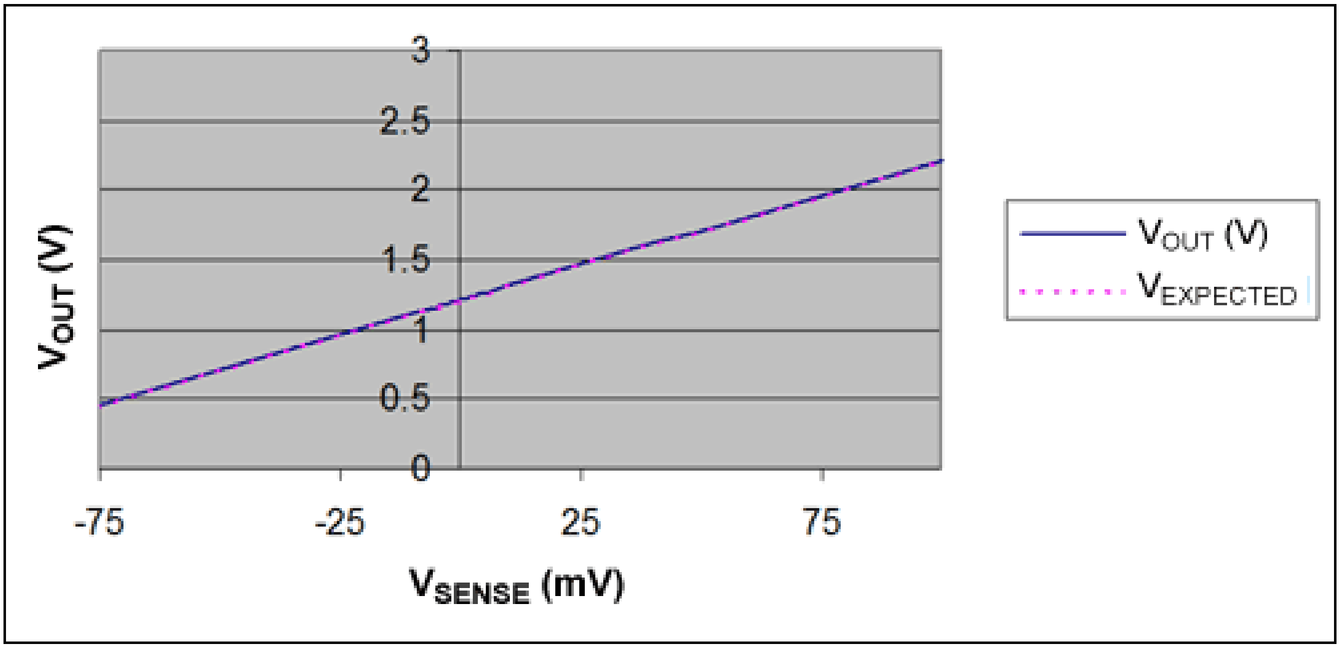

Figure 3. The transfer characteristic of a MAX4172 circuit.

Conditions for MAX4173 circuit are:

V_{BAT} = 8V
V_{CC} = V_{BAT} for MAX4173
V_{CC} = 5V for MAX4230
V_{REF} = 1.5V

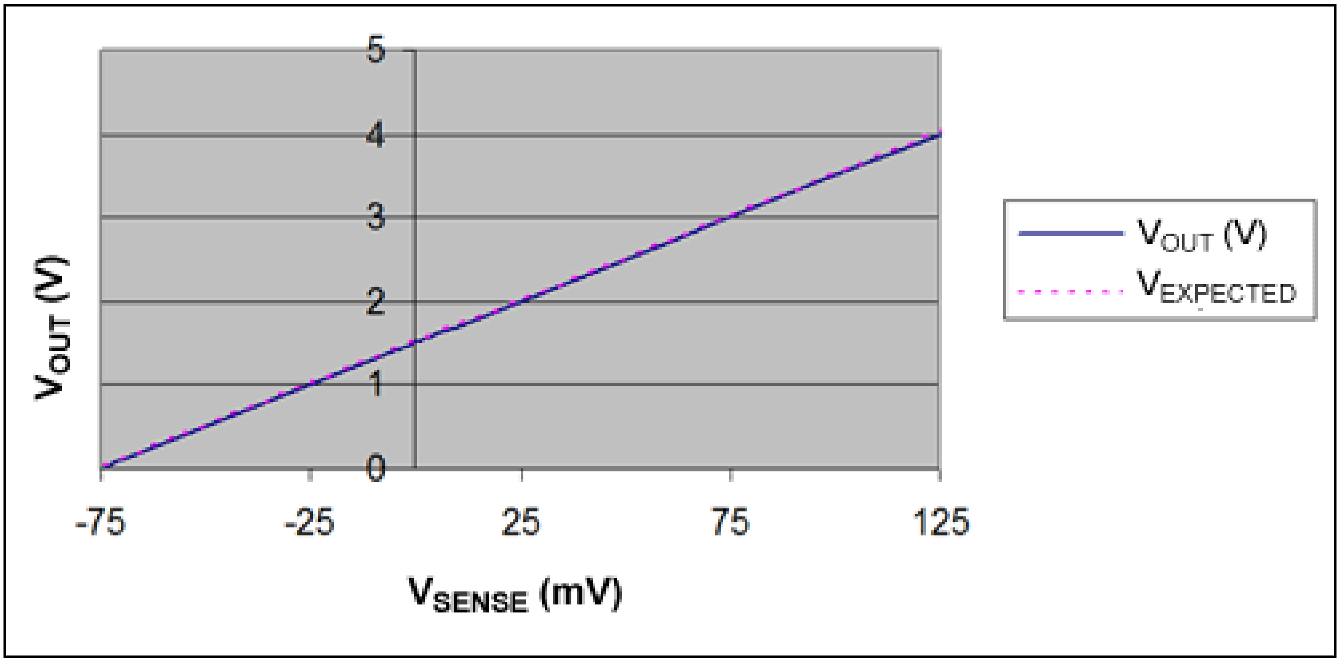

Figure 4. The transfer characteristic of a MAX4173 circuit.

Maxim also offers integrated bidirectional current-sense amplifiers:

- MAX4081: 76V bidirectional current-sense amplifier
- MAX4069–MAX4072: 24V bidirectional current-sense amplifier with/without internal reference

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Application Note 3906: http://www.maxim-ic.com/an3906

More Information
For technical questions and support: http://www.maxim-ic.com/support
For samples: http://www.maxim-ic.com/samples
Other questions and comments: http://www.maxim-ic.com/contact

Related Parts

MAX4073: QuickView -- Full (PDF) Data Sheet -- Free Samples

MAX4080: QuickView -- Full (PDF) Data Sheet -- Free Samples

MAX4081: QuickView -- Full (PDF) Data Sheet -- Free Samples

MAX4172: QuickView -- Full (PDF) Data Sheet -- Free Samples

MAX4173: QuickView -- Full (PDF) Data Sheet -- Free Samples

AN3906, AN 3906, APP3906, Appnote3906, Appnote 3906

19-1184; Rev 0; 12/96

Low-Cost, Precision, High-Side Current-Sense Amplifier

General Description

The MAX4172 is a low-cost, precision, high-side current-sense amplifier for portable PCs, telephones, and other systems where battery/DC power-line monitoring is critical. High-side power-line monitoring is especially useful in battery-powered systems, since it does not interfere with the battery charger's ground path. Wide bandwidth and ground-sensing capability make the MAX4172 suitable for closed-loop battery-charger and general-purpose current-source applications. The 0V to 32V input common-mode range is independent of the supply voltage, which ensures that current-sense feedback remains viable, even when connected to a battery in deep discharge.

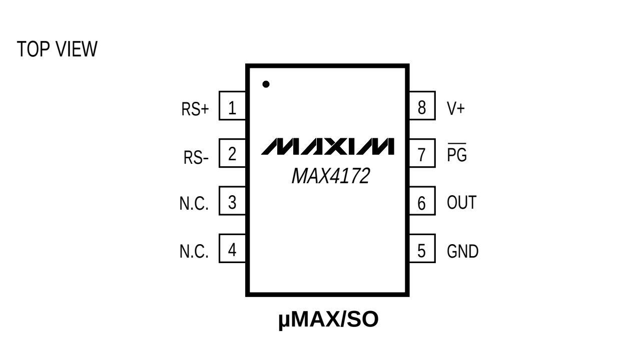
To provide a high level of flexibility, the MAX4172 functions with an external sense resistor to set the range of load current to be monitored. It has a current output that can be converted to a ground-referred voltage with a single resistor, accommodating a wide range of battery voltages and currents.

An open-collector power-good output ($\overline{PG}$) indicates when the supply voltage reaches an adequate level to guarantee proper operation of the current-sense amplifier. The MAX4172 operates with a 3.0V to 32V supply voltage, and is available in a space-saving, 8-pin µMAX or SO package.

Applications

Portable PCs: Notebooks/Subnotebooks/Palmtops
Battery-Powered/Portable Equipment
Closed-Loop Battery Chargers/Current Sources
Smart-Battery Packs
Portable/Cellular Phones
Portable Test/Measurement Systems
Energy Management Systems

Pin Configuration



Features

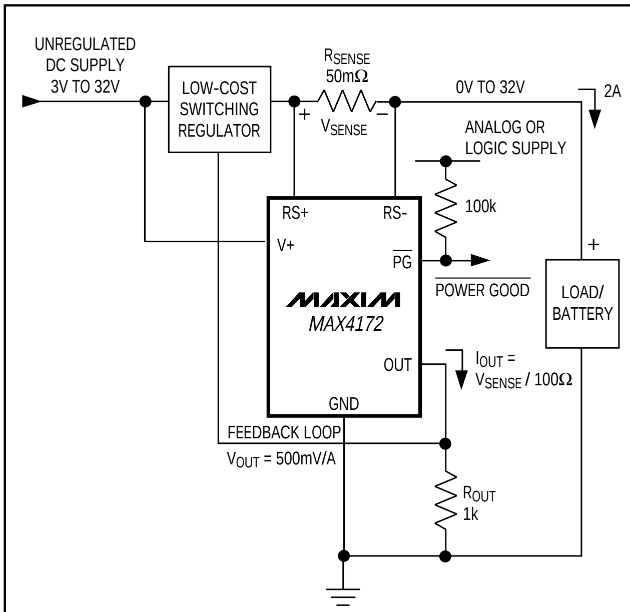
- **Low-Cost, High-Side Current-Sense Amplifier**
- **±0.5% Typical Full-Scale Accuracy Over Temperature**
- **3V to 32V Supply Operation**
- **0V to 32V Input Range—Independent of Supply Voltage**
- **800kHz Bandwidth [V_{SENSE} = 100mV (1C)]**
  200kHz Bandwidth [V_{SENSE} = 6.25mV (C/16)]
- **Available in Space-Saving µMAX and SO Packages**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX4172ESA	-40°C to +85°C	8 SO
MAX4172EUA	-40°C to +85°C	8 µMAX*

**Contact factory for availability.*

Typical Operating Circuit



LOW-COST BATTERY CHARGER/CURRENT SOURCE

ABSOLUTE MAXIMUM RATINGS

V+, RS+, RS-, $\overline{PG}$ ....-0.3V to +36V
OUT ....-0.3V to (V+ + 0.3V)
Differential Input Voltage, V_{RS+} - V_{RS-} ....±700mV
Current into Any Pin..±50mA
Continuous Power Dissipation (T_A = +70°C)
SO (derate 5.88mW/°C above +70°C)..........................471mW
µMAX (derate 4.10mW/°C above +70°C) 330mW
Operating Temperature Range
MAX4172E_A..-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+ = +3V to +32V; RS+, RS- = 0V to 32V; T_A = T_{MIN} to T_{MAX}; unless otherwise noted. Typical values are at V+ = +12V, RS+ = 12V, T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Operating Voltage Range	V+			3		32	V
Input Voltage Range	V_{RS-}			0		32	V
Supply Current	I_{V+}	I_{OUT} = 0mA			0.8	1.6	mA
Input Offset Voltage	V_{OS}	V+ = 12V, V_{RS+} = 12V	MAX4172ESA		±0.1	±0.75	mV
			MAX4172EUA		±0.2	±1.6	
		$V_{RS+} \leq$ 2.0V			4		
Positive Input Bias Current	I_{RS+}	V_{RS+} > 2.0V, I_{OUT} = 0mA		0	27	42.5	µA
		$V_{RS+} \leq$ 2.0V, I_{OUT} = 0mA		-325		42.5	
Negative Input Bias Current	I_{RS-}	V_{RS+} > 2.0V		0	50	85	µA
		$V_{RS+} \leq$ 2.0V		-650		85	
Maximum V_{SENSE} Voltage				150	175		mV
Low-Level Current Error		V_{SENSE} = 6.25mV, V+ = 12V, V_{RS+} = 12V (Note 1)	MAX4172ESA			±8.0	µA
			MAX4172EUA			±15	
Output Current Error		V_{SENSE} = 100mV, V+ = 12V, V_{RS+} = 12V	MAX4172ESA, T_A = -40°C to 0°C			±20	µA
			MAX4172EUA, T_A = -40°C to 0°C			±50	
			MAX4172ESA, T_A = 0°C to +85°C			±10	
			MAX4172EUA, T_A = 0°C to +85°C			±15	
OUT Power-Supply Rejection Ratio	ΔI_{OUT} / ΔV+	3V $\leq$ V+ $\leq$ 32V, V_{RS+} > 2.0V			0.2		µA/V
OUT Common-Mode Rejection Ratio	ΔI_{OUT} / ΔV_{RS+}	2.0V < V_{RS+} < 32V			0.03		µA/V

ELECTRICAL CHARACTERISTICS (continued)

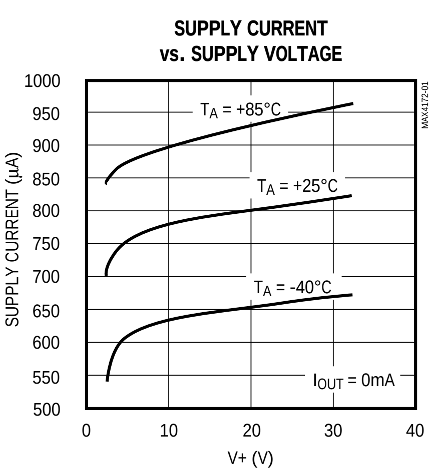
($V+ = +3V$ to $+32V$; RS+, RS- = 0V to 32V; $T_A = T_{MIN}$ to T_{MAX}; unless otherwise noted. Typical values are at $V+ = +12V$, $RS+ = 12V$, $T_A = +25°C$.)

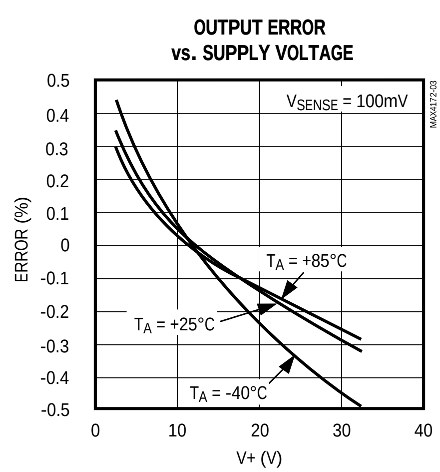
PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Maximum Output Voltage (OUT)		$I_{OUT} \le 1.5mA$				V+ - 1.2	V
Bandwidth		V_{SENSE} = 100mV			800		kHz
		V_{SENSE} = 6.25mV (Note 1)			200		
Maximum Output Current	I_{OUT}			1.5	1.75		mA
Transconductance	G_m	$G_m = I_{OUT} / (V_{RS+} - V_{RS-})$, V_{SENSE} = 100mV, $V_{RS+} > 2.0V$	T_A = 0°C to +85°C	9.8	10	10.2	mA/V
			T_A = -40°C to 0°C	9.7	10	10.3	
V+ Threshold for $\overline{PG}$ Output Low (Note 2)		V+ rising			2.77		V
		V+ falling			2.67		
$\overline{PG}$ Output Low Voltage	V_{OL}	I_{SINK} = 1.2mA, V+ = 2.9V, T_A = +25°C				0.4	V
Leakage Current into $\overline{PG}$		V+ = 2.5V, T_A = +25°C				1	µA
Power-Off Input Leakage Current (RS+, RS-)		V+ = 0V, $V_{RS+} = V_{RS-}$ = 32V			0.1	1	µA
OUT Rise Time		V_{SENSE} = 0mV to 100mV, 10% to 90%			400		ns
OUT Fall Time		V_{SENSE} = 100mV to 0mV, 90% to 10%			800		ns
OUT Settling Time to 1%		V_{SENSE} = 5mV to 100mV	Rising		1.3		µs
			Falling		6		
OUT Output Resistance		V_{SENSE} = 150mV			20		MΩ

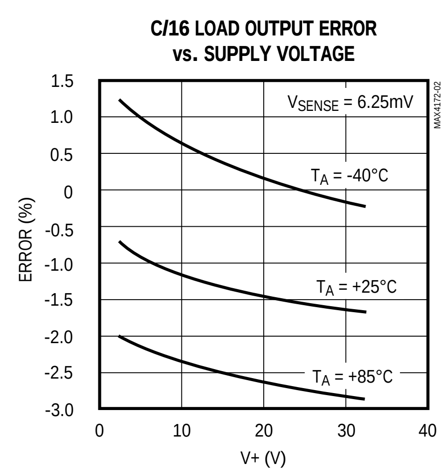
Note 1: 6.25mV = 1/16 of typical full-scale sense voltage (C/16).
Note 2: Valid operation of the MAX4172 is guaranteed by design when $\overline{PG}$ is low.

Typical Operating Characteristics

($V+ = +12V$, $V_{RS+} = 12V$, $R_{OUT} = 1kΩ$, $T_A = +25°C$, unless otherwise noted.)



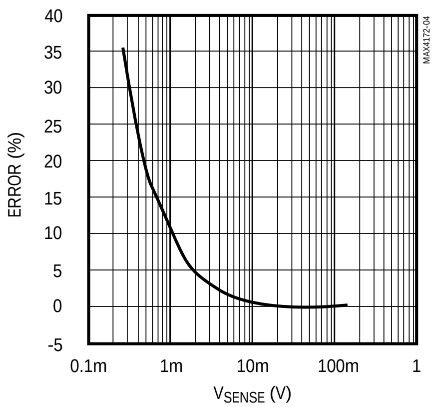




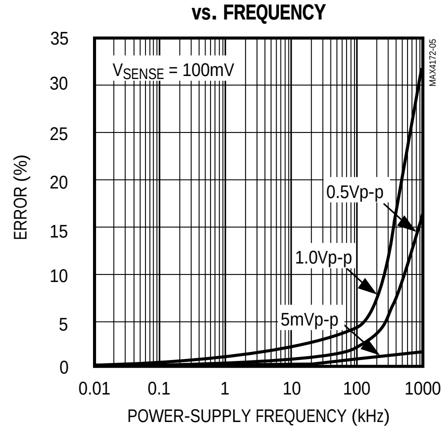
Typical Operating Characteristics (continued)

($V+ = +12V$, $V_{RS+} = 12V$, $R_{OUT} = 1k\Omega$, $T_A = +25°C$, unless otherwise noted.)

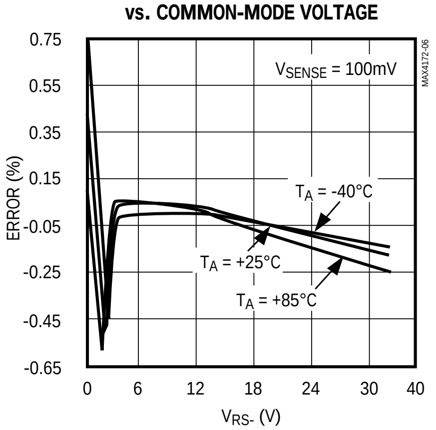
ERROR vs. SENSE VOLTAGE



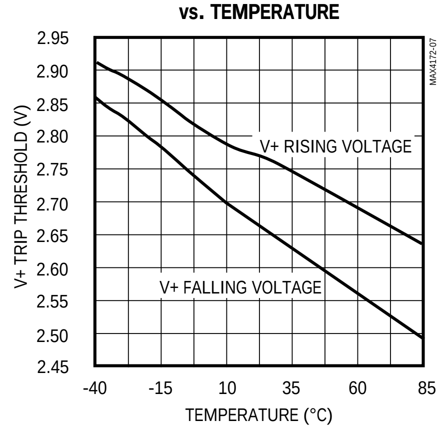
POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



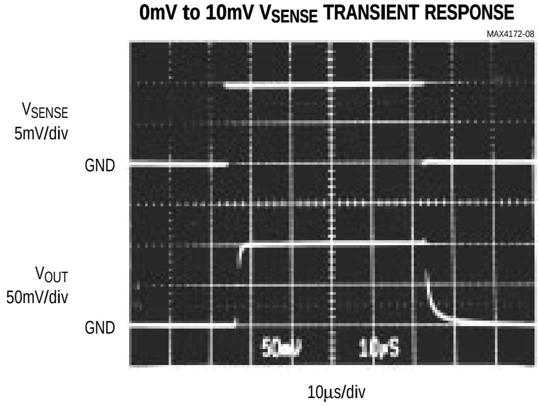
OUTPUT ERROR vs. COMMON-MODE VOLTAGE



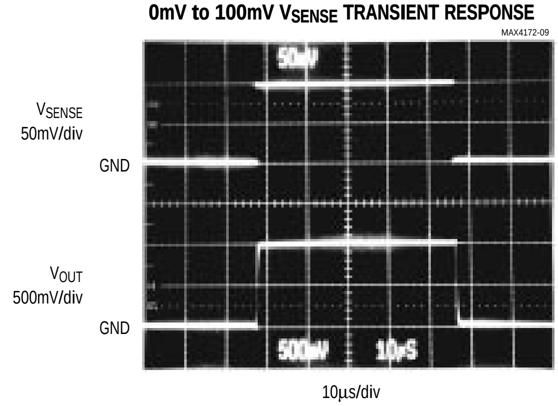
V+ THRESHOLD FOR $\overline{PG}$ OUTPUT LOW vs. TEMPERATURE



0mV to 10mV V_{SENSE} TRANSIENT RESPONSE



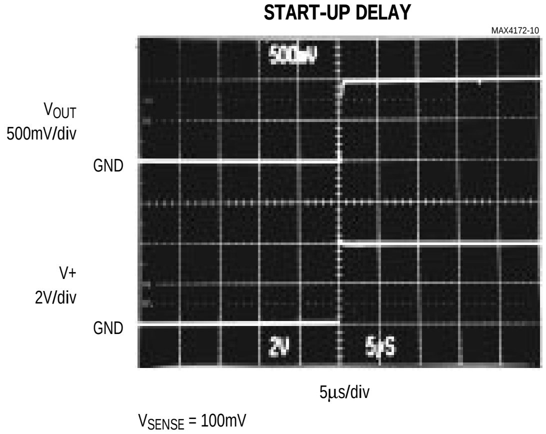
0mV to 100mV V_{SENSE} TRANSIENT RESPONSE



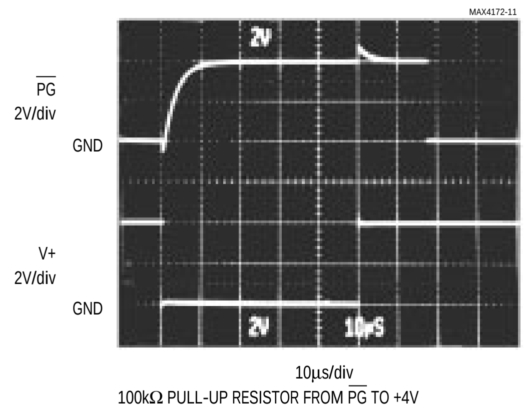
Typical Operating Characteristics (continued)

(V+ = +12V, V_{RS+} = 12V, R_{OUT} = 1kΩ, T_A = +25°C, unless otherwise noted.)

START-UP DELAY



V+ to $\overline{PG}$ POWER-UP DELAY



Pin Description

PIN	NAME	FUNCTION
1	RS+	Power connection to the external sense resistor. The “+” indicates the direction of current flow.
2	RS-	Load-side connection for the external sense resistor. The “-” indicates the direction of current flow.
3, 4	N.C.	No Connect. No internal connection. Leave open or connect to GND.
5	GND	Ground
6	OUT	Current Output. OUT is proportional to the magnitude of the sense voltage (V_{RS+} - V_{RS-}). A 1kΩ resistor from OUT to ground will result in a voltage equal to 10V/V of sense voltage.
7	$\overline{PG}$	Power Good Open-Collector Logic Output. A low level indicates that V+ is sufficient to power the MAX4172, and adequate time has passed for power-on transients to settle out.
8	V+	Supply Voltage Input for the MAX4172

Detailed Description

The MAX4172 is a unidirectional, high-side current-sense amplifier with an input common-mode range that is independent of supply voltage. This feature not only allows the monitoring of current flow into a battery in deep discharge, but also enables high-side current sensing at voltages far in excess of the supply voltage (V+).

The MAX4172 current-sense amplifier's unique topology simplifies current monitoring and control. The MAX4172's amplifier operates as shown in Figure 1. The battery/load current flows through the external sense resistor (R_{SENSE}), from the RS+ node to the RS- node. Current flows through R_{G1} and Q1, and into the current mirror, where it is multiplied by a factor of 50 before appearing at OUT.

To analyze the circuit of Figure 1, assume that current flows from RS+ to RS-, and that OUT is connected to GND through a resistor. Since A1's inverting input is high impedance, no current flows though R_{G2} (neglecting the input bias current), so A1's negative input is equal to V_{SOURCE} - (I_{LOAD} x R_{SENSE}). A1's open-loop gain forces its positive input to essentially the same voltage level as the negative input. Therefore, the drop across R_{G1} equals I_{LOAD} x R_{SENSE}. Then, since I_{RG1}

flows through R_{G1}, I_{RG1} x R_{G1} = I_{LOAD} x R_{SENSE}. The internal current mirror multiplies I_{RG1} by a factor of 50 to give I_{OUT} = 50 x I_{RG1}. Substituting I_{OUT} / 50 for I_{RG1}, (I_{OUT} / 50) x R_{G1} = I_{LOAD} x R_{SENSE}, or:

$$I_{OUT} = 50 \times I_{LOAD} \times (R_{SENSE} / R_{G1})$$

The internal current gain of 50 and the factory-trimmed resistor R_{G1} combine to result in the MAX4172 transconductance (G_m) of 10mA/V. G_m is defined as being equal to I_{OUT} / (V_{RS+} - V_{RS-}). Since (V_{RS+} - V_{RS-}) = I_{LOAD} x R_{SENSE}, the output current (I_{OUT}) can be calculated with the following formula:

$$I_{OUT} = G_m \times (V_{RS+} - V_{RS-}) =$$
$$(10mA/V) \times (I_{LOAD} \times R_{SENSE})$$

Current Output

The output voltage equation for the MAX4172 is given below:

$$V_{OUT} = (G_m) \times (R_{SENSE} \times R_{OUT} \times I_{LOAD})$$

where V_{OUT} = the desired full-scale output voltage, I_{LOAD} = the full-scale current being sensed, R_{SENSE} = the current-sense resistor, R_{OUT} = the voltage-setting resistor, and G_m = MAX4172 transconductance (10mA/V).

The full-scale output voltage range can be set by changing the R_{OUT} resistor value, but the output voltage must be no greater than V+ - 1.2V. The above equation can be modified to determine the R_{OUT} required for a particular full-scale range:

$$R_{OUT} = (V_{OUT}) / (I_{LOAD} \times R_{SENSE} \times G_m)$$

OUT is a high-impedance current source that can be integrated by connecting it to a capacitive load.

$\overline{PG}$ Output

The $\overline{PG}$ output is an open-collector logic output that indicates the status of the MAX4172's V+ power supply. A logic low on the $\overline{PG}$ output indicates that V+ is sufficient to power the MAX4172. This level is temperature dependent (see *Typical Operating Characteristics* graphs), and is typically 2.7V at room temperature. The internal PG comparator has a 100mV (typical) hysteresis to prevent possible oscillations caused by repeated toggling of the $\overline{PG}$ output, making the device ideal for power-management systems lacking soft-start capability. An internal delay (15µs typical) in the $\overline{PG}$ comparator allows adequate time for power-on transients to settle out. The $\overline{PG}$ status indicator greatly simplifies the design of closed-loop systems by ensuring that the components in the control loop have sufficient voltage to operate correctly.

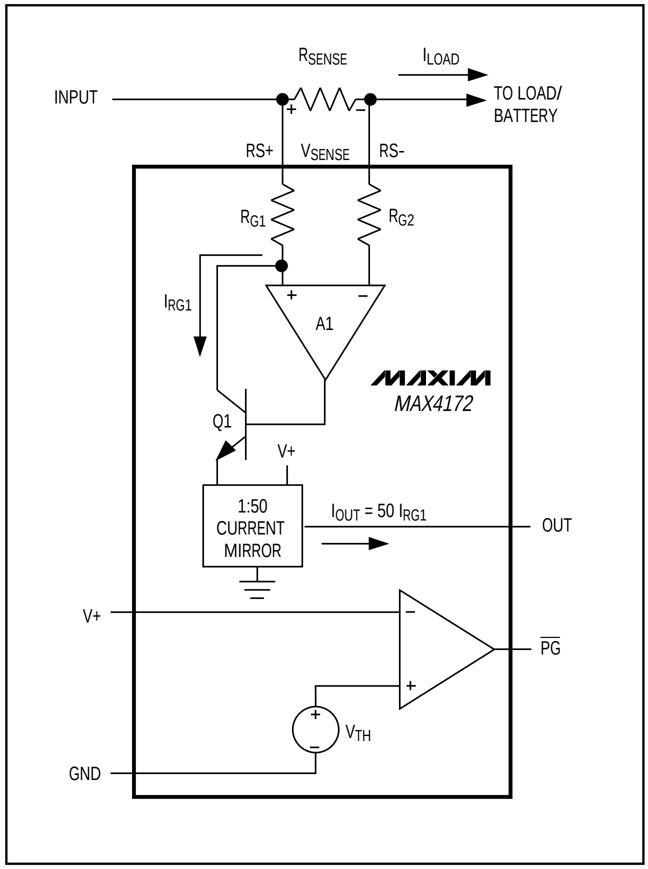


Figure 1. Functional Diagram

Applications Information

Suggested Component Values for Various Applications

The *Typical Operating Circuit* is useful in a wide variety of applications. Table 1 shows suggested component values and indicates the resulting scale factors for various applications required to sense currents from 100mA to 10A.

Adjust the R_{SENSE} value to monitor higher or lower current levels. Select R_{SENSE} using the guidelines and formulas in the following section.

Sense Resistor, R_{SENSE}

Choose R_{SENSE} based on the following criteria:

- **Voltage Loss:** A high R_{SENSE} value causes the power-source voltage to degrade through IR loss. For minimal voltage loss, use the lowest R_{SENSE} value.

Table 1. Suggested Component Values

FULL-SCALE LOAD CURRENT (A)	CURRENT-SENSE RESISTOR, R_{SENSE} (mΩ)	OUTPUT RESISTOR, R_{OUT} (kΩ)	FULL-SCALE OUTPUT VOLTAGE, V_{OUT} (V)	SCALE FACTOR, V_{OUT}/I_{SENSE} (V/A)
0.1	1000	3.48	3.48	34.8
1	100	3.48	3.48	3.48
5	20	3.48	3.48	0.696
10	10	3.48	3.48	0.348

- **Accuracy:** A high R_{SENSE} value allows lower currents to be measured more accurately. This is because offsets become less significant when the sense voltage is larger. For best performance, select R_{SENSE} to provide approximately 100mV of sense voltage for the full-scale current in each application.
- **Efficiency and Power Dissipation:** At high current levels, the I^2R losses in R_{SENSE} can be significant. Take this into consideration when choosing the resistor value and its power dissipation (wattage) rating. Also, the sense resistor's value might drift if it is allowed to heat up excessively.
- **Inductance:** Keep inductance low if I_{SENSE} has a large high-frequency component. Wire-wound resistors have the highest inductance, while metal film is somewhat better. Low-inductance metal-film resistors are also available. Instead of being spiral wrapped around a core, as in metal-film or wire-wound resistors, they are a straight band of metal and are available in values under 1Ω.
- **Cost:** If the cost of R_{SENSE} is an issue, you might want to use an alternative solution, as shown in Figure 2. This solution uses the PC board traces to create a sense resistor. Because of the inaccuracies of the copper resistor, the full-scale current value must be adjusted with a potentiometer. Also, copper's resistance temperature coefficient is fairly high (approximately 0.4%/°C).

In Figure 2, assume that the load current to be measured is 10A, and that you have determined a 0.3-inch-wide, 2-ounce copper to be appropriate. The resistivity of 0.1-inch-wide, 2-ounce (70µm thickness) copper is 30mΩ/ft. For 10A, you might want R_{SENSE} = 5mΩ for a 50mV drop at full scale. This resistor requires about 2 inches of 0.1-inch-wide copper trace.

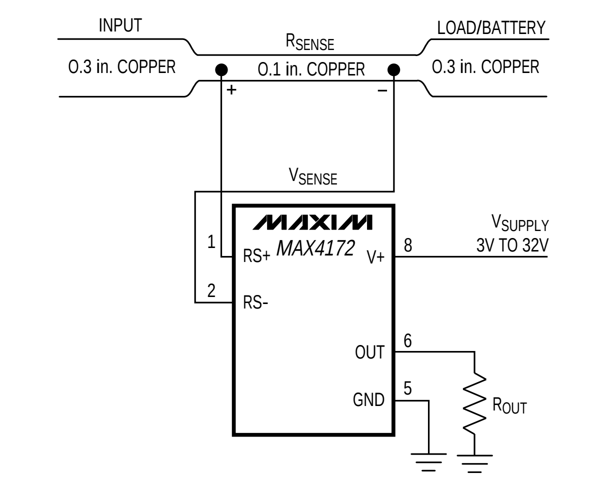


Figure 2. MAX4172 Connections Showing Use of PC Board

Current-Sense Adjustment (Resistor Range, Output Adjust)

Choose R_{OUT} after selecting R_{SENSE}. Choose R_{OUT} to obtain the full-scale voltage you require, given the full-scale I_{OUT} determined by R_{SENSE}. OUT's high impedance permits using R_{OUT} values up to 200kΩ with minimal error. OUT's load impedance (e.g., the input of an op amp or ADC) must be much greater than R_{OUT} (e.g., 100 x R_{OUT}) to avoid degrading measurement accuracy.

High-Current Measurement

The MAX4172 can achieve high-current measurements by using low-value sense resistors, which can be paralleled to further increase the current-sense limit. As an alternative, PC board traces can be adjusted over a wide range.

Power-Supply Bypassing and Grounding

In most applications, grounding the MAX4172 requires no special precautions. However, in high-current systems, large voltage drops can develop across the ground plane, which can add to or subtract from V_{OUT}. Use a single-point star ground for the highest current-measurement accuracy.

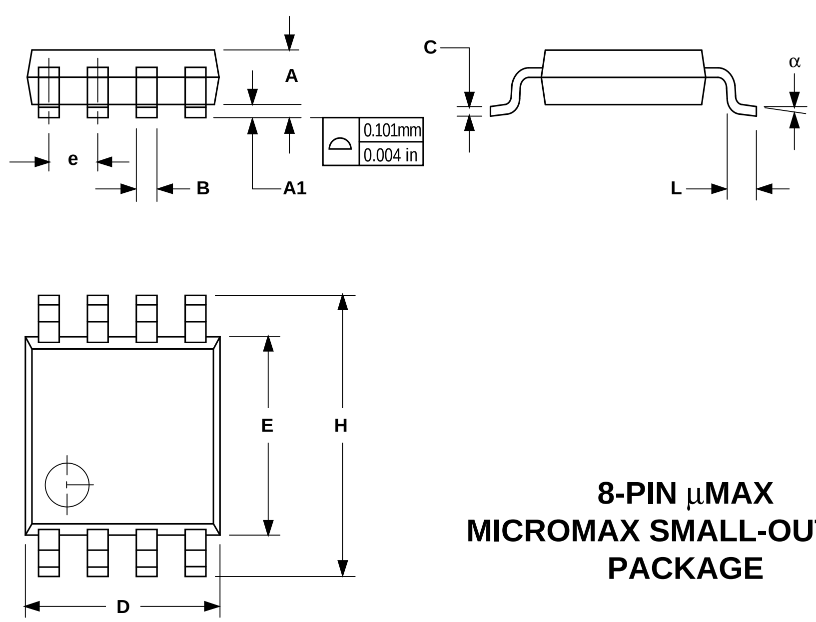
The MAX4172 requires no special bypassing and responds quickly to transient changes in line current. If the noise at OUT caused by these transients is a problem, you can place a 1µF capacitor at the OUT pin to ground. You can also place a large capacitor at the RS terminal (or load side of the MAX4172) to decouple the load, reducing the current transients. These capacitors are not required for MAX4172 operation or stability. The RS+ and RS- inputs can be filtered by placing a capacitor (e.g., 1µF) between them to average the sensed current.

Chip Information

TRANSISTOR COUNT: 177

SUBSTRATE CONNECTED TO GND

Package Information



DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.036	0.044	0.91	1.11
A1	0.004	0.008	0.10	0.20
B	0.010	0.014	0.25	0.36
C	0.005	0.007	0.13	0.18
D	0.116	0.120	2.95	3.05
E	0.116	0.120	2.95	3.05
e	0.0256		0.65	
H	0.188	0.198	4.78	5.03
L	0.016	0.026	0.41	0.66
α	0°	6°	0°	6°

21-0036D

8-PIN µMAX MICROMAX SMALL-OUTLINE PACKAGE

19-1434; Rev 3; 12/04

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

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.

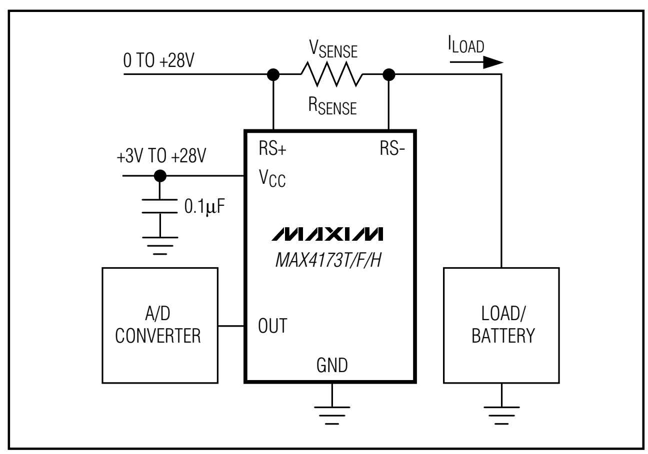
Applications

- 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**
- ♦ **±0.3mV Input Offset Voltage (MAX4173T)**
- ♦ **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	AABO
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.

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, 10s) .... +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} = 0V, 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	
OUT Low Voltage	V_{OL}	MAX4173TEUT, V_{CC} = +5V, V_{RS+} = 0.89V, V_{SENSE} = 0mV; T_A = +25°C		1.2	5	mV
		MAX4173TEUT, V_{CC} = +5V, V_{RS+} = 0.89V, V_{SENSE} = 0mV; T_A = -40°C to +85°C			40	

ELECTRICAL CHARACTERISTICS (continued)

(V_{RS+} = 0 to +28V, V_{CC} = +3V to +28V, V_{SENSE} = 0V, 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	ΔA_V	MAX4173T/F V_{SENSE} = +10mV to +150mV, V_{CC} = V_{RS+} = 12V	T_A = +25°C		0.5	±2.5	%
			T_A = -40°C to +85°C			4.0	
		MAX4173H V_{SENSE} = +10mV to +100mV, V_{CC} = V_{RS+} = 12V	T_A = +25°C		0.5	±2.5	
			T_A = -40°C to +85°C			4.0	
Input Offset Voltage (Note 6)	V_{OS}	MAX4173TEUT	T_A = +25°C		0.3	±3	mV
			T_A = -40°C to +85°C			±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 7)			10		µs

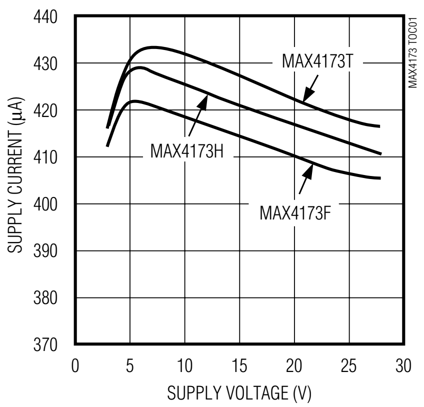
Note 1: All devices are 100% production tested at T_A = +25°C. All temperature limits are guaranteed by design.
Note 2: Guaranteed by Total Output Voltage Error Test.
Note 3: Total OUT Voltage Error is the sum of gain and offset voltage errors.
Note 4: +6.25mV = 1/16 of +100mV full-scale voltage.
Note 5: V_{SENSE} such that output stage is in saturation.
Note 6: V_{OS} is extrapolated from the Gain Accuracy tests.
Note 7: The device does not experience phase reversal when overdriven.

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

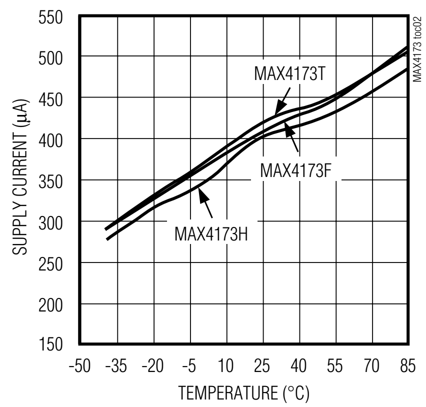
Typical Operating Characteristics

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

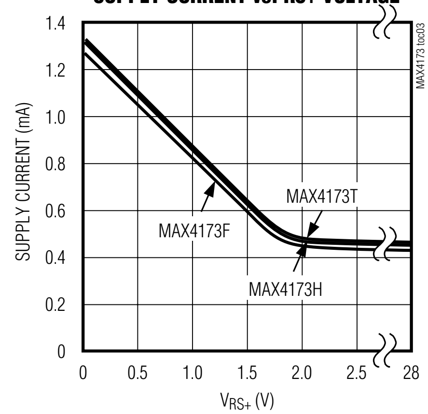
SUPPLY CURRENT vs. SUPPLY VOLTAGE



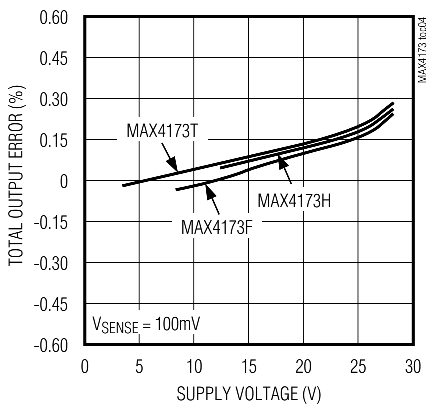
SUPPLY CURRENT vs. TEMPERATURE



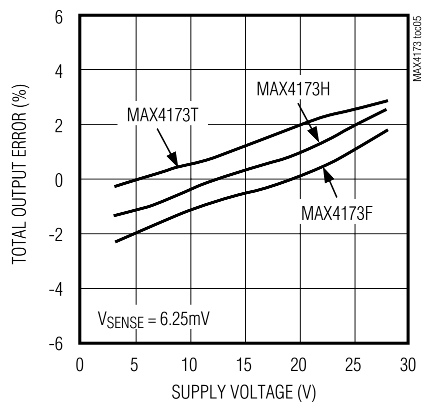
SUPPLY CURRENT vs. RS+ VOLTAGE



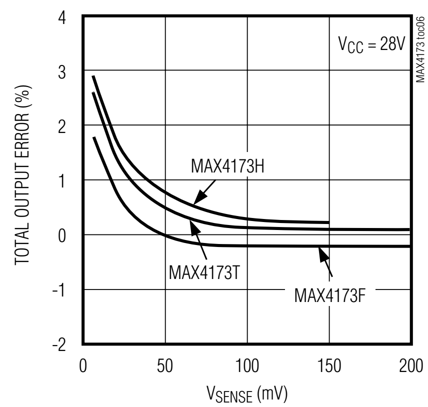
TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE



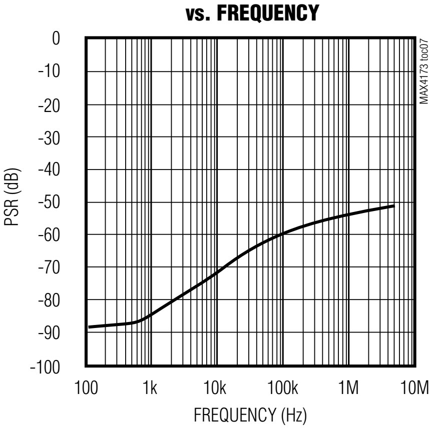
TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE



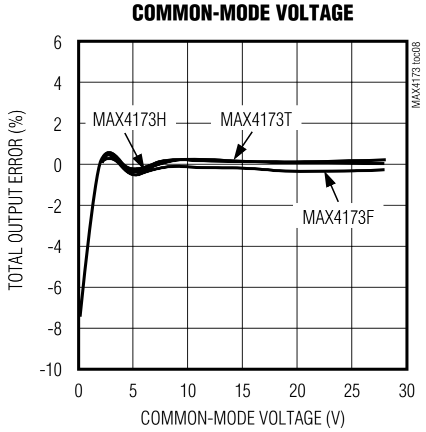
TOTAL OUTPUT ERROR vs. FULL-SCALE SENSE VOLTAGE



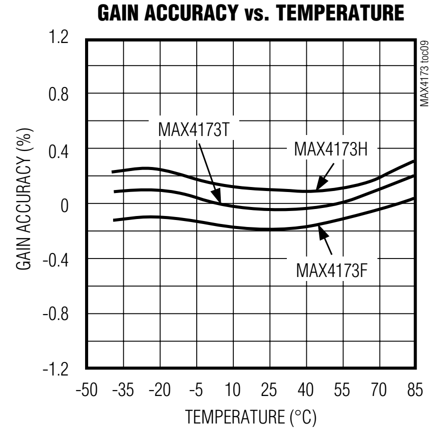
POWER-SUPPLY REJECTION vs. FREQUENCY



TOTAL OUTPUT ERROR vs. COMMON-MODE VOLTAGE



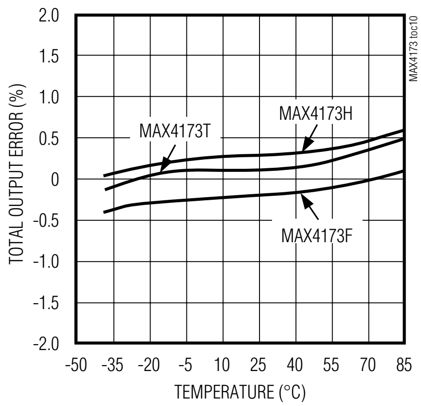
GAIN ACCURACY vs. TEMPERATURE



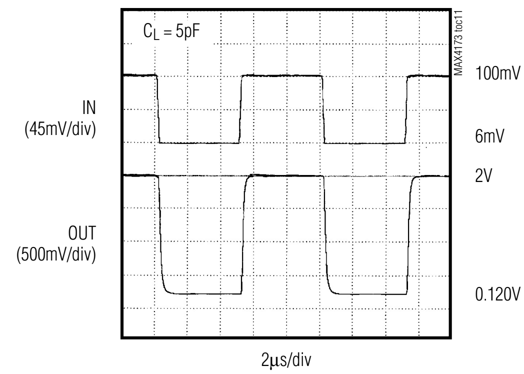
Typical Operating Characteristics (continued)

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

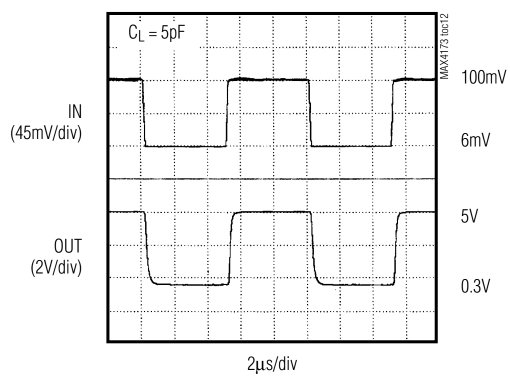
TOTAL OUTPUT ERROR vs. TEMPERATURE



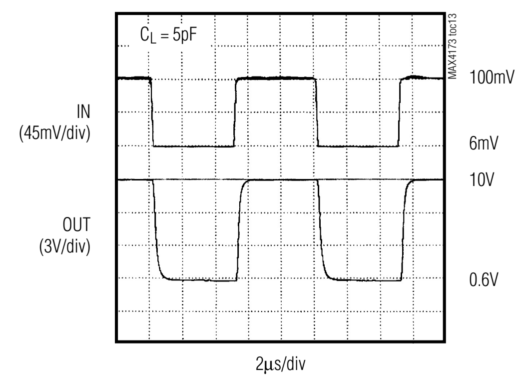
MAX4173T LARGE-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 6mV to 100mV)



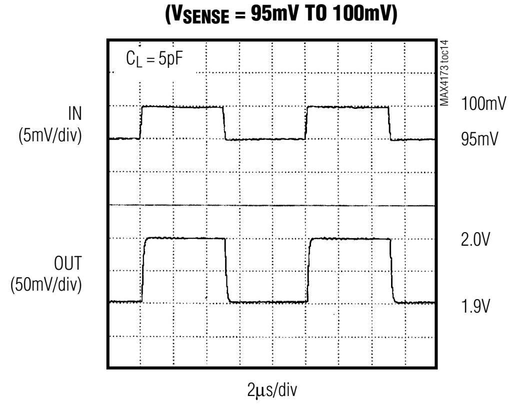
MAX4173F LARGE-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 6mV to 100mV)



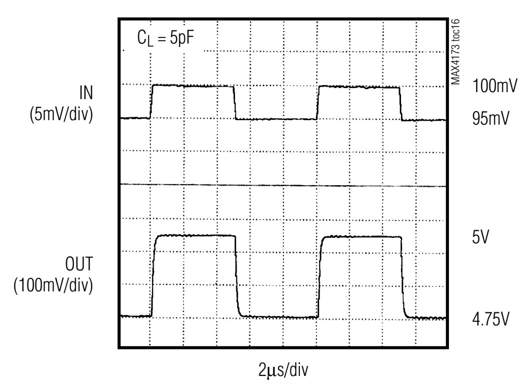
MAX4173H LARGE-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 6mV to 100mV)



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



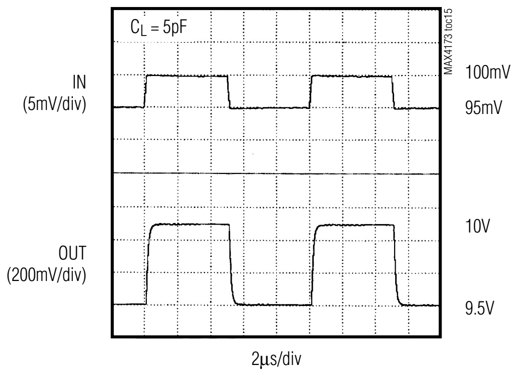
MAX4173F SMALL-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 95mV TO 100mV)



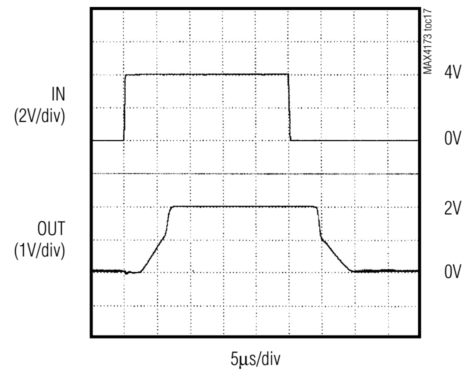
Typical Operating Characteristics (continued)

(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.

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, β, 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.

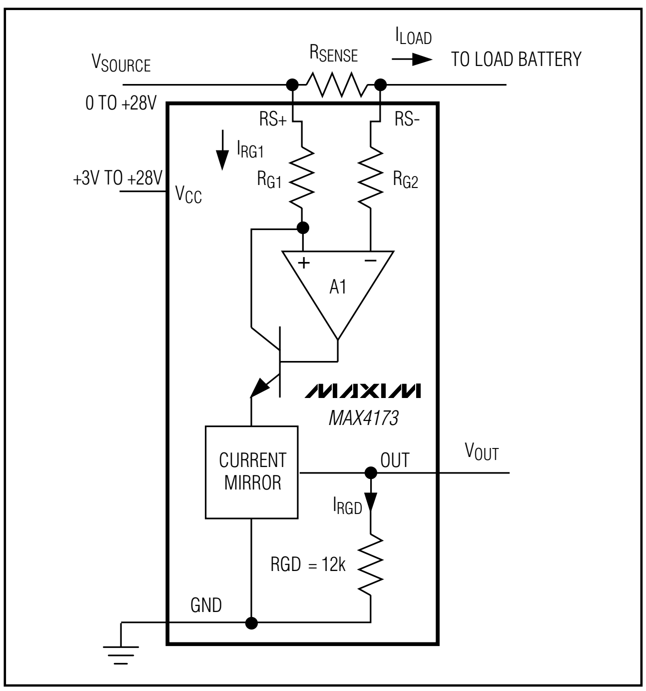


Figure 1. Functional Diagram

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 30mΩ/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 5mΩ) 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 12kΩ 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

Table 1. Recommended Component Values

FULL-SCALE LOAD CURRENT I_{LOAD} (A)	CURRENT-SENSE RESISTOR R_{SENSE} (mΩ)	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

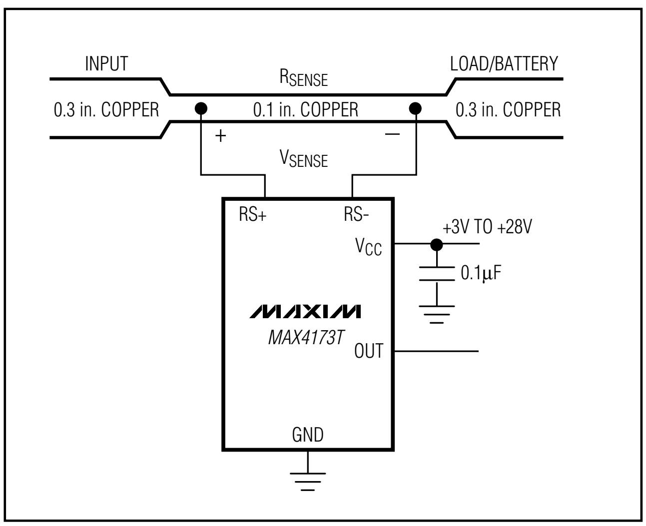


Figure 2. MAX4173 Connections Showing Use of PC Board

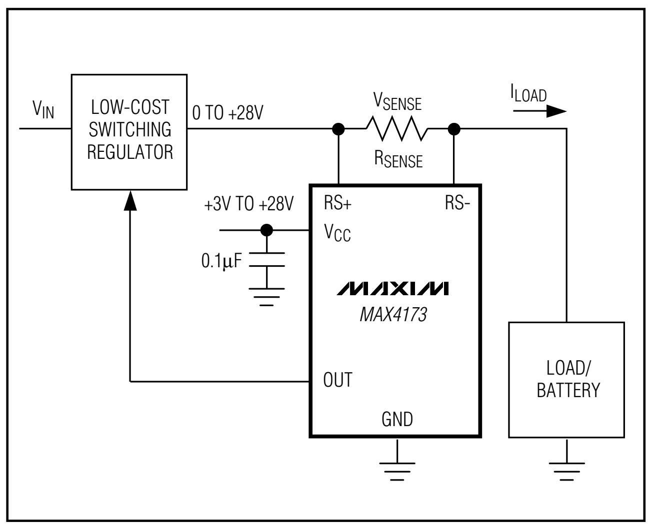


Figure 3. Current Source

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:

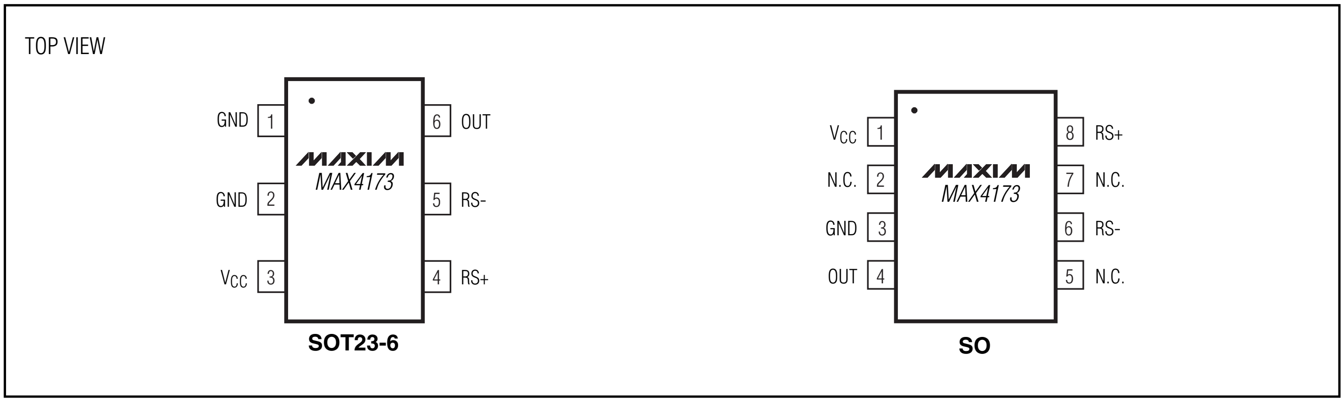
$$\%_{ERROR} = 100\left(\frac{R_{LOAD}}{12k\Omega + R_{LOAD}} - 1\right)$$

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.

Pin Configurations



Chip Information

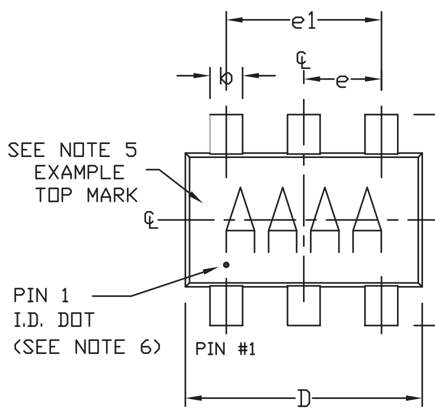
TRANSISTOR COUNT: 187

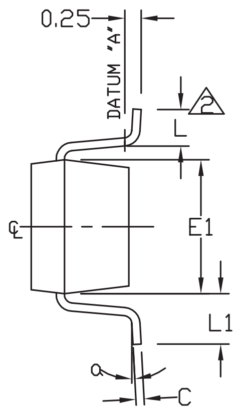
Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier

Package Information

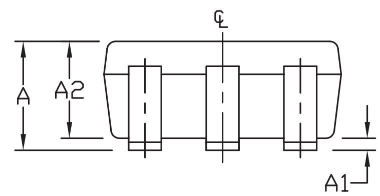
(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

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	0.60
L1	0.60 REF.	
e1	1.90 BSC.	
e	0.95 BSC.	
α	0°	10°



NOTES:

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. MOLD FLASH, PROTRUSION OR METAL BURR SHOULD NOT EXCEED 0.25 MM.
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.
7. MEETS JEDEC MO178, VARIATION AB.
8. SOLDER THICKNESS MEASURED AT FLAT SECTION OF LEAD BETWEEN 0.08mm AND 0.15mm FROM LEADTIP.
9. LEAD TO BE COPLANAR WITHIN 0.1 MM.

DALLAS SEMICONDUCTOR MAXIM

PROPRIETARY INFORMATION

TITLE: PACKAGE OUTLINE, SOT-23, 6L

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	21-0058	F	1/1

Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

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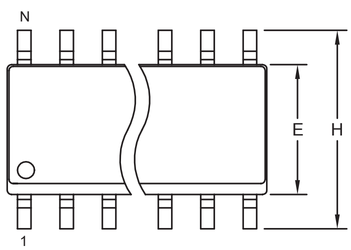
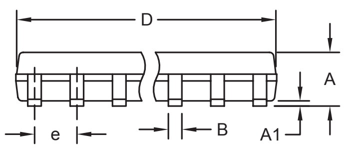


TOP VIEW

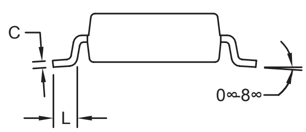
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.004	0.010	0.10	0.25
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
e	0.050 BSC		1.27 BSC	
E	0.150	0.157	3.80	4.00
H	0.228	0.244	5.80	6.20
L	0.016	0.050	0.40	1.27

VARIATIONS:

	INCHES		MILLIMETERS			
DIM	MIN	MAX	MIN	MAX	N	MS012
D	0.189	0.197	4.80	5.00	8	AA
D	0.337	0.344	8.55	8.75	14	AB
D	0.386	0.394	9.80	10.00	16	AC



FRONT VIEW



SIDE VIEW

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED 0.15mm (.006”).
3. LEADS TO BE COPLANAR WITHIN 0.10mm (.004”).
4. CONTROLLING DIMENSION: MILLIMETERS.
5. MEETS JEDEC MS012.
6. N = NUMBER OF PINS.

DALLAS SEMICONDUCTOR MAXIM
PROPRIETARY INFORMATION
TITLE:
PACKAGE OUTLINE, .150" SOIC

APPROVAL	DOCUMENT CONTROL NO.	REV.	
	21-0041	B	1/1

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