



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

## General Description

The MAX4372 low-cost, precision, high-side current-sense amplifier is available in a tiny, space-saving SOT23-5 package. Offered in three gain versions (T = +20V/V, F = +50V/V, and H = +100V/V), this device operates from a single +2.7V to +28V supply and consumes only 30 $\mu$ A. It features a voltage output that eliminates the need for gain-setting resistors and is ideal for today's notebook computers, cell phones, and other systems where battery/DC current monitoring is critical.

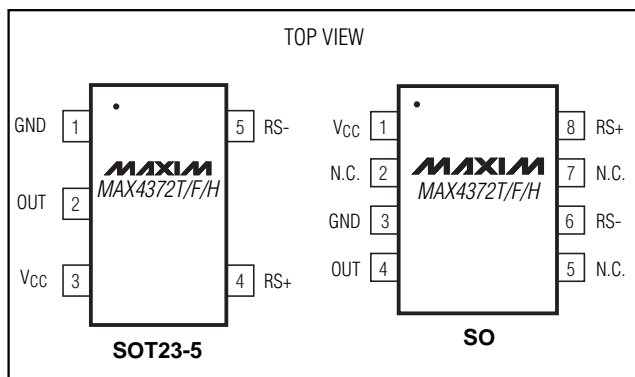
High-side current monitoring is especially useful in battery-powered systems since it does not interfere with the ground path of the battery charger. The input common-mode range of 0 to +28V is independent of the supply voltage and ensures that the current-sense feedback remains viable even when connected to a 2-cell battery pack in deep discharge.

The user can set the full-scale current reading by choosing the device (T, F, or H) with the desired voltage gain and selecting the appropriate external sense resistor. This capability offers a high level of integration and flexibility, resulting in a simple and compact current-sense solution. For higher bandwidth applications, refer to the MAX4173T/F/H data sheet.

## Applications

Power-Management Systems  
 General-System/Board-Level Current Monitoring  
 Notebook Computers  
 Portable/Battery-Powered Systems  
 Smart-Battery Packs/Chargers  
 Cell Phones  
 Precision-Current Sources

## Pin Configurations



## Features

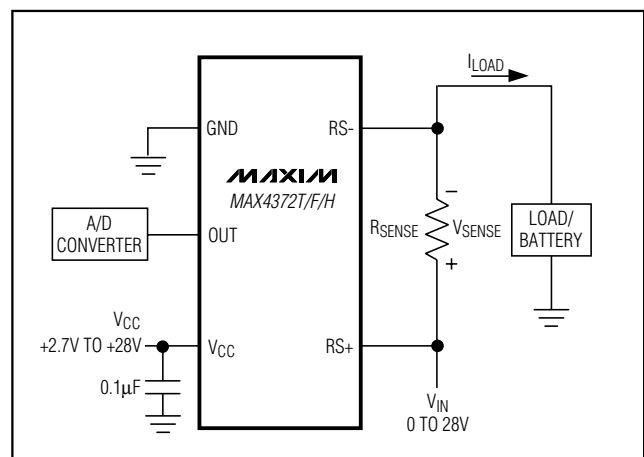
- ◆ Low-Cost, Compact Current-Sense Solution
- ◆ 30 $\mu$ A Supply Current
- ◆ +2.7V to +28V Operating Supply
- ◆ 0.18% Full-Scale Accuracy
- ◆ Low 1.5 $\Omega$  Output Impedance
- ◆ Three Gain Versions Available
  - +20V/V (MAX4372T)
  - +50V/V (MAX4372F)
  - +100V/V (MAX4372H)
- ◆ Wide 0 to +28V Common-Mode Range, Independent of Supply Voltage
- ◆ Available in Space-Saving SOT23-5 Package

## Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE	TOP MARK
MAX4372TEUK-T	-40°C to +85°C	5 SOT23-5	ADIU
MAX4372TESA	-40°C to +85°C	8 SO	—
MAX4372FEUK-T	-40°C to +85°C	5 SOT23-5	ADIV
MAX4372FESA	-40°C to +85°C	8 SO	—
MAX4372HEUK-T	-40°C to +85°C	5 SOT23-5	ADIW
MAX4372HESA	-40°C to +85°C	8 SO	—

**Note:** Gain values are as follows: +20V/V for the T version, +50V/V for the F version, and +100V/V for the H version.

## Typical Operating Circuit



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

## ABSOLUTE MAXIMUM RATINGS

V<sub>CC</sub>, RS+, RS- to GND .....-0.3V to +30V  
 OUT to GND .....-0.3V to +15V  
 Differential Input Voltage (V<sub>RS+</sub> - V<sub>RS-</sub>) .....±0.3V  
 Current into Any Pin .....±10mA

Continuous Power Dissipation (T<sub>A</sub> = +70°C)  
 5-Pin SOT23 (derate 7.1mW/°C above +70°C).....571mW  
 8-Pin SO (derate 5.88mW/°C above +70°C).....471mW  
 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<sub>RS+</sub> = 0 to +28V, V<sub>CC</sub> = +2.7V to +28V, V<sub>SENSE</sub> = 0, R<sub>LOAD</sub> = 1MΩ, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted. Typical values are at T<sub>A</sub> = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Operating Voltage Range (Note 2)	V <sub>CC</sub>		2.7		28	V
Common-Mode Input Range (Note 3)	V <sub>CMR</sub>		0		28	V
Common-Mode Rejection	CMR	V <sub>RS+</sub> > 2V		85		dB
Supply Current	I <sub>CC</sub>	V <sub>RS+</sub> > 2V, V <sub>SENSE</sub> = 5mV		30	60	μA
Leakage Current	I <sub>RS+</sub> , I <sub>RS-</sub>	V <sub>CC</sub> = 0		0.05	1.2	μA
Input Bias Current	I <sub>RS+</sub>	V <sub>RS+</sub> > 2V	0		1	μA
		V <sub>RS+</sub> ≤ 2V	-25		2	
	I <sub>RS-</sub>	V <sub>RS+</sub> > 2V	0		2	
		V <sub>RS+</sub> ≤ 2V	-50		2	
Full-Scale Sense Voltage (Note 4)	V <sub>SENSE</sub>	Gain = +20V/V or +50V/V		150		mV
		Gain = +100V/V		100		
Full-Scale Accuracy (Note 5)		V <sub>SENSE</sub> = 100mV, V <sub>CC</sub> = 12V, V <sub>RS+</sub> = 12V, T <sub>A</sub> = +25°C (Note 6)		±0.18	±3	%
Total OUT Voltage Error (Note 5)		V <sub>SENSE</sub> = 100mV, V <sub>CC</sub> = 12V, V <sub>RS+</sub> = 12V (Note 6)			±6	%
		V <sub>SENSE</sub> = 100mV, V <sub>CC</sub> = 28V, V <sub>RS+</sub> = 28V (Note 6)		±0.15	±7	
		V <sub>SENSE</sub> = 100mV, V <sub>CC</sub> = 12V, V <sub>RS+</sub> = 0.1V (Note 6)		±1	±28	
		V <sub>SENSE</sub> = 6.25mV, V <sub>CC</sub> = 12V, V <sub>RS+</sub> = 12V (Note 7)		±0.15		
OUT Low Voltage		V <sub>CC</sub> = 2.7V	I <sub>OUT</sub> = 10μA	2.6		mV
			I <sub>OUT</sub> = 100μA	9	65	
OUT High Voltage	V <sub>CC</sub> - V <sub>OH</sub>	V <sub>CC</sub> = 2.7V, I <sub>OUT</sub> = -500μA		0.1	0.25	V

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

MAX4372T/F/H

## ELECTRICAL CHARACTERISTICS (continued)

( $V_{RS+} = 0$  to  $+28V$ ,  $V_{CC} = +2.7V$  to  $+28V$ ,  $V_{SENSE} = 0$ ,  $R_{LOAD} = 1M\Omega$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
-3dB Bandwidth	BW	$V_{RS+} = 12V$ , $V_{CC} = 12V$ , $C_{LOAD} = 10pF$	$V_{SENSE} = 100mV$ , gain = $+20V/V$		275		kHz
			$V_{SENSE} = 100mV$ , gain = $+50V/V$		200		
			$V_{SENSE} = 100mV$ , gain = $+100V/V$		110		
			$V_{SENSE} = 6.25mV$		50		
Gain		MAX4372T			20		V/V
		MAX4372F			50		
		MAX4372H			100		
Gain Accuracy		$V_{SENSE} = 20mV$ to $100mV$	$T_A = +25^\circ C$		$\pm 0.25$	$\pm 2.5$	%
			$T_A = -40^\circ C$ to $+85^\circ C$			$\pm 5.5$	
OUT Settling Time to 1% of Final Value		Gain = $+20V/V$ , $V_{CC} = 12V$ , $V_{RS+} = 12V$ , $C_{LOAD} = 10pF$	$V_{SENSE} = 6.25mV$ to $100mV$		20		$\mu s$
			$V_{SENSE} = 100mV$ to $6.25mV$		20		
Capacitive Load Stability		No sustained oscillations			1000		pF
OUT Output Resistance	$R_{OUT}$	$V_{SENSE} = 100mV$			1.5		$\Omega$
Power-Supply Rejection	PSR	$V_{OUT} = 2V$ , $V_{RS+} > 2V$		75	85		dB
Power-Up Time to 1% of Final Value		$V_{CC} = 12V$ , $V_{RS+} = 12V$ , $V_{SENSE} = 100mV$ , $C_{LOAD} = 10pF$			0.5		ms
Saturation Recovery Time (Note 8)		$V_{CC} = 12V$ , $V_{RS+} = 12V$ , $C_{LOAD} = 10pF$			0.1		ms

**Note 1:** All devices are 100% production tested at  $T_A = +25^\circ C$ . All temperature limits are guaranteed by design.

**Note 2:** Guaranteed by PSR test.

**Note 3:** Guaranteed by OUT Voltage Error test.

**Note 4:** Output voltage is internally clamped not to exceed 12V.

**Note 5:** Total OUT voltage error is the sum of gain and offset voltage errors.

**Note 6:** Measured at  $I_{OUT} = -500\mu A$  ( $R_{LOAD} = 4k\Omega$  for gain =  $+20V/V$ ,  $R_{LOAD} = 10k\Omega$  for gain =  $+50V/V$ ,  $R_{LOAD} = 20k\Omega$  for gain =  $+100V/V$ ).

**Note 7:**  $+6.25mV = 1/16$  of  $+100mV$  full-scale voltage (C/16).

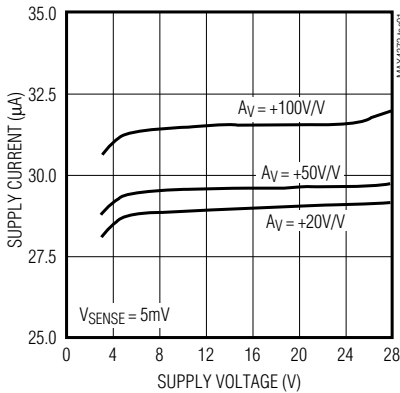
**Note 8:** The device will not reverse phase when overdriven.

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

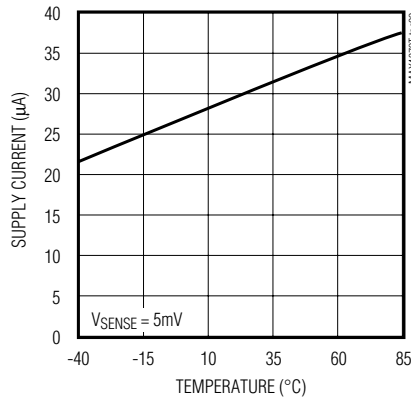
## Typical Operating Characteristics

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

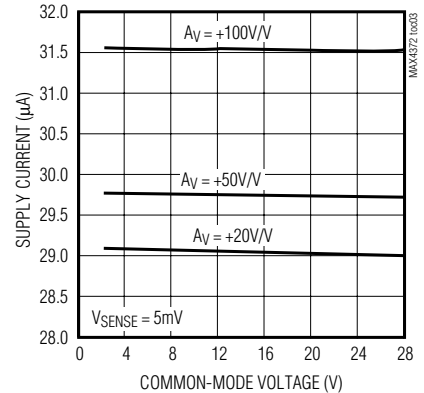
**SUPPLY CURRENT vs. SUPPLY VOLTAGE**



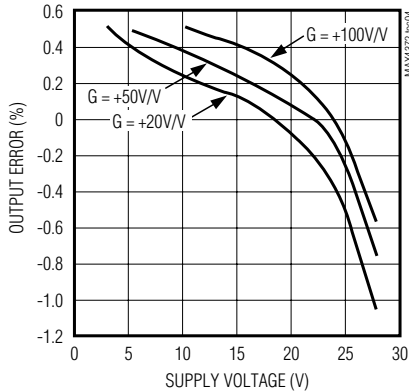
**SUPPLY CURRENT vs. TEMPERATURE**



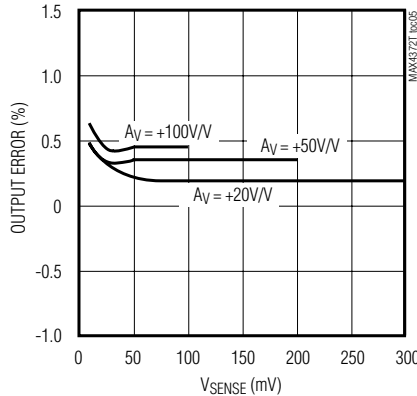
**SUPPLY CURRENT vs. COMMON-MODE VOLTAGE**



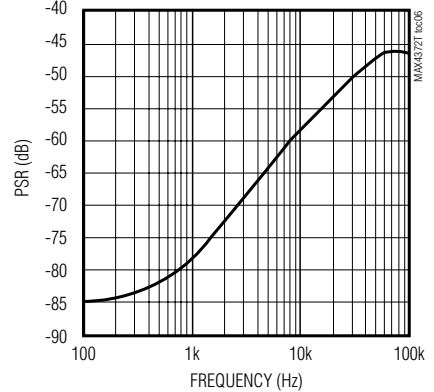
**TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE**



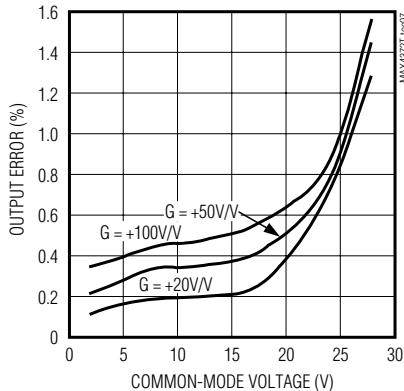
**TOTAL OUTPUT ERROR vs.  $V_{SENSE}$**



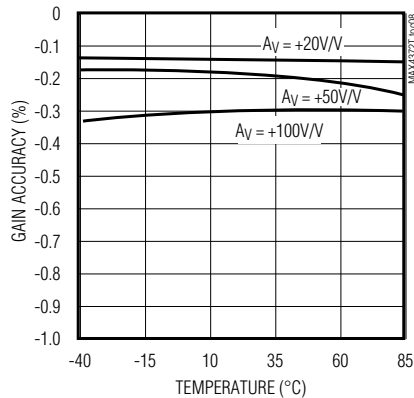
**POWER-SUPPLY REJECTION vs. FREQUENCY**



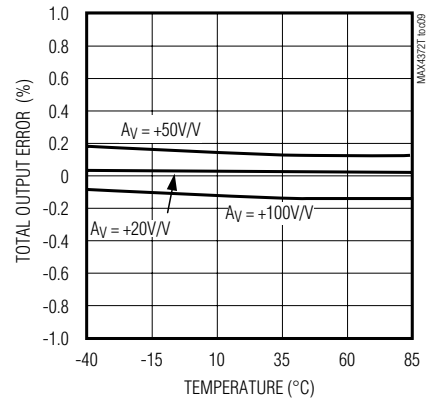
**TOTAL OUTPUT ERROR vs. COMMON-MODE VOLTAGE**



**GAIN ACCURACY vs. TEMPERATURE**



**TOTAL OUTPUT ERROR vs. TEMPERATURE**



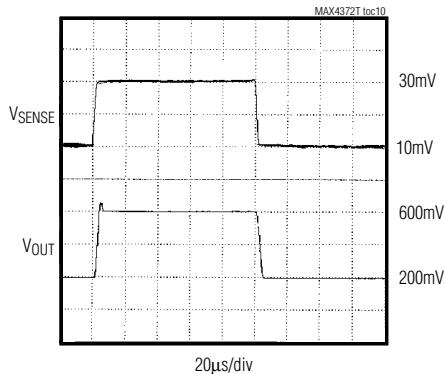
# Low-Cost, SOT23, Micropower, High-Side Current-Sense Amplifier with Voltage Output

## Typical Operating Characteristics (continued)

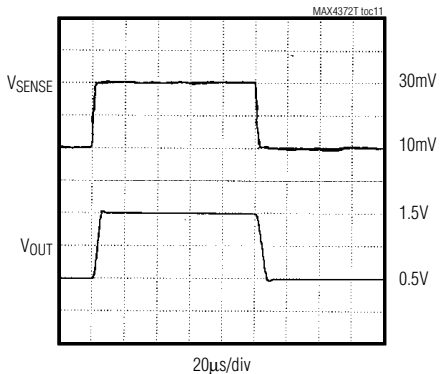
( $V_{CC} = +12V$ ,  $V_{RS+} = 12V$ ,  $V_{SENSE} = 100mV$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)

**MAX4372T/F/H**

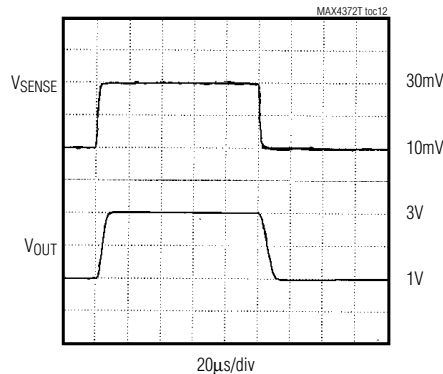
**MAX4372T**  
SMALL-SIGNAL TRANSIENT RESPONSE



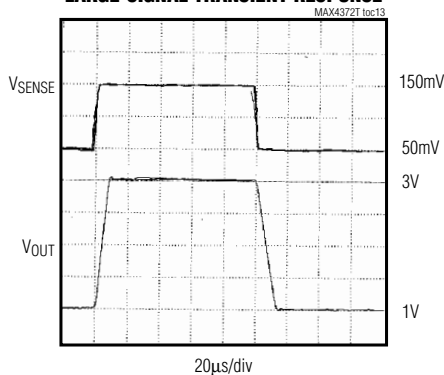
**MAX4372F**  
SMALL-SIGNAL TRANSIENT RESPONSE



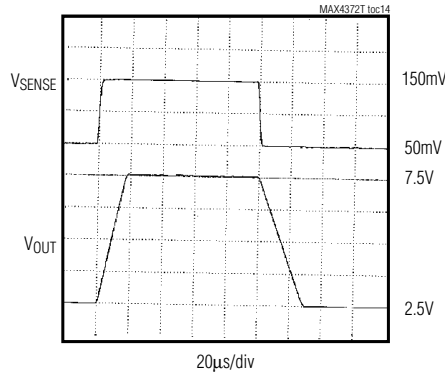
**MAX4372H**  
SMALL-SIGNAL TRANSIENT RESPONSE



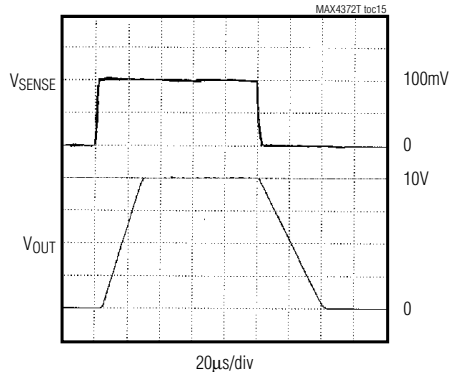
**MAX4372T**  
LARGE-SIGNAL TRANSIENT RESPONSE



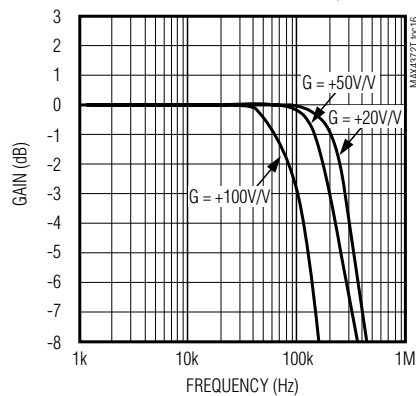
**MAX4372F**  
LARGE-SIGNAL TRANSIENT RESPONSE



**MAX4372H**  
LARGE-SIGNAL TRANSIENT RESPONSE



**SMALL-SIGNAL GAIN vs. FREQUENCY**



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

## Pin Description

PIN		NAME	FUNCTION
SOT23-5	SO		
1	3	GND	Ground
2	4	OUT	Output Voltage. $V_{OUT}$ is proportional to the magnitude of $V_{SENSE}$ ( $V_{RS+} - V_{RS-}$ ).
3	1	VCC	Supply Voltage
4	8	RS+	Power Connection to the External Sense Resistor
5	6	RS-	Load-Side Connection to the External Sense Resistor
—	2, 5, 7	N.C.	No Connection. Not internally connected.

## Detailed Description

The MAX4372 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 flow out of a battery in deep discharge, and also enables high-side current sensing at voltages far in excess of the supply voltage ( $V_{CC}$ ).

Current flows through the sense resistor, generating a sense voltage (Figure 1). Since A1's inverting input is high impedance, the voltage on the negative terminal equals  $V_{IN} - V_{SENSE}$ . A1 forces its positive terminal to match its negative terminal; therefore, the voltage across  $R_{G1}$  ( $V_{IN} - V_{1-}$ ) equals  $V_{SENSE}$ . This creates a current to flow through  $R_{G1}$  equal to  $V_{SENSE} / R_{G1}$ . The transistor and current mirror amplify the current by a factor of  $\beta$ . This makes the current flowing out of the current mirror equal to:

$$I_M = \beta V_{SENSE} / R_{G1}$$

A2's positive terminal presents high impedance, so this current flows through  $R_{GD}$ , with the following result:

$$V_{2+} = R_{GD} \beta \cdot V_{SENSE} / R_{G1}$$

$R_1$  and  $R_2$  set the closed-loop gain for A2, which amplifies  $V_{2+}$ , yielding:

$$V_{OUT} = R_{GD} \cdot \beta \cdot V_{SENSE} / R_{G1} (1 + R_2 / R_1)$$

The gain of the device equals:

$$\frac{V_{OUT}}{V_{SENSE}} = R_{GD} \cdot \beta (1 + R_2 / R_1) / R_{G1}$$

## Applications Information

### Recommended Component Values

The MAX4372 operates over a wide variety of current ranges with different sense resistors. Table 1 lists common resistor values for typical operation of the MAX4372.

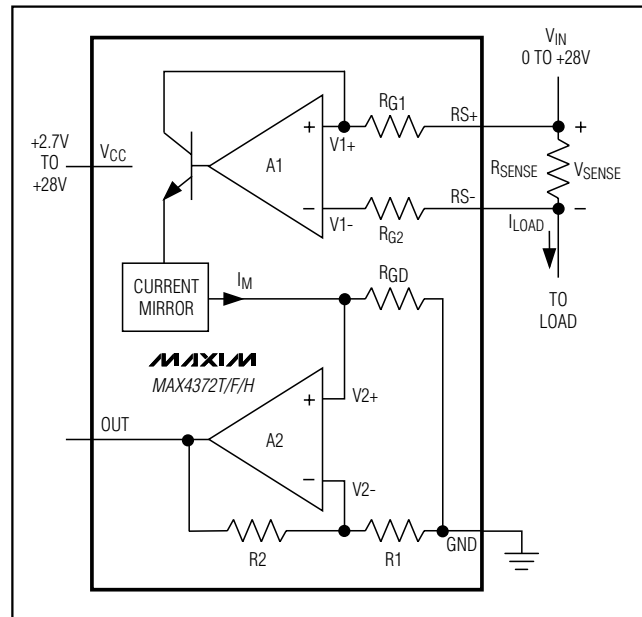


Figure 1. Functional Diagram

### Choosing RSENSE

Given the gain and maximum load current, select  $R_{SENSE}$  such that  $V_{CC} - V_{OUT}$  does not exceed +0.25V and  $V_{OUT}$  does not exceed +10V. To measure lower currents more accurately, use a high value for  $R_{SENSE}$ . A higher value develops a higher sense voltage, which overcomes offset voltage errors of the internal current amplifier.

In applications monitoring very high current, ensure  $R_{SENSE}$  is able to dissipate its own  $I^2R$  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.

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

MAX4372T/F/H

Table 1. Recommended Component Values

FULL-SCALE LOAD CURRENT, $I_{LOAD}$ (A)	CURRENT-SENSE RESISTOR, $R_{SENSE}$ (m $\Omega$ )	GAIN (V/V)	FULL-SCALE OUTPUT VOLTAGE (FULL-SCALE $V_{SENSE} = 100\text{mV}$ ), $V_{OUT}$ (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

## Using a PC Board 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 about 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, self-heating will introduce a nonlinearity error. Do not exceed the maximum power dissipation of the copper trace.

For example, the MAX4372T (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.

## Chip Information

TRANSISTOR COUNT: 225

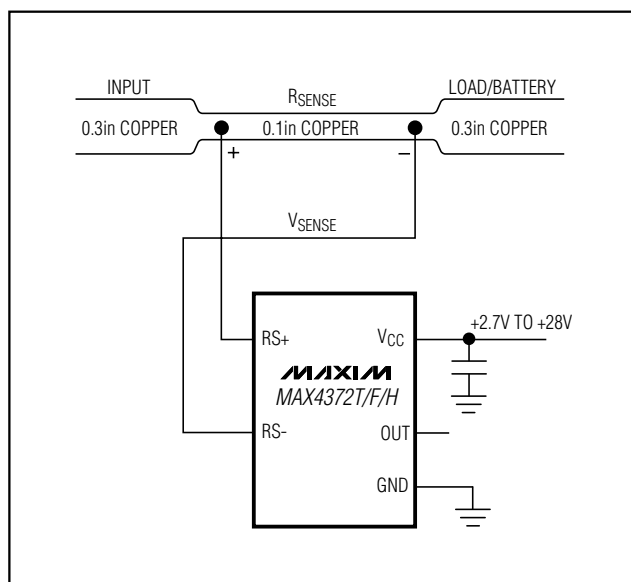
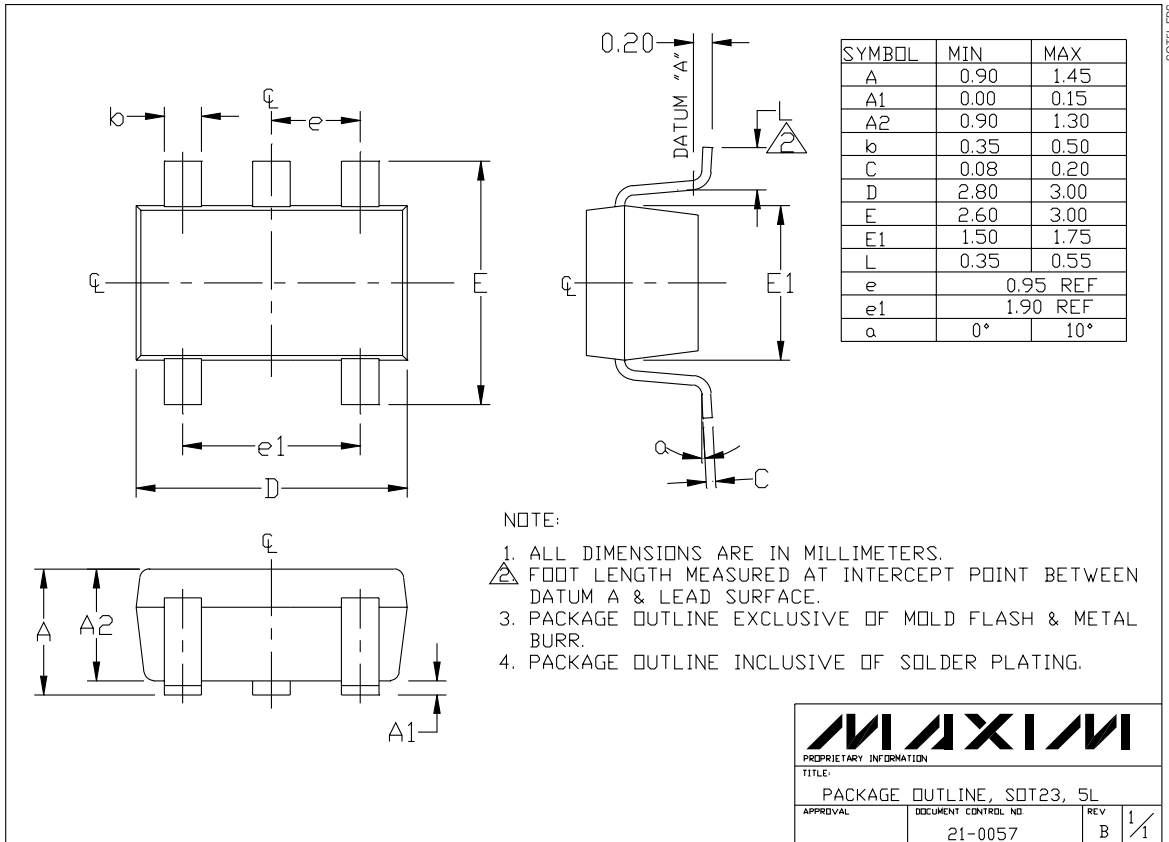


Figure 2. Connections Showing Use of PC Board

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

## Package Information



SOT23LEFS

**MAXIM**  
 PROPRIETARY INFORMATION  
 TITLE: PACKAGE OUTLINE, SOT23, 5L  
 APPROVAL: \_\_\_\_\_ DOCUMENT CONTROL NO: 21-0057 REV B 1/1

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