



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

**MAX4372T/F/H**

## General Description

The MAX4372 low-cost, precision, high-side current-sense amplifier is available in a tiny, space-saving SOT23-5-pin 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.

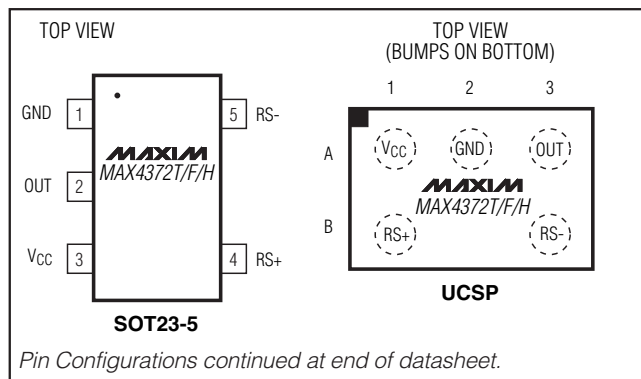
High-side current monitoring is especially useful in battery-powered systems since it does not interfere with the ground path of the battery charger. The input common-mode range of 0 to 28V is independent of the supply voltage and ensures that the current-sense feedback remains viable even when connected 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
- ◆ 0.3mV Input Offset Voltage
- ◆ 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 a Space-Saving 5-Pin SOT23 Package and 3 x 2 UCSP™ (1mm x 1.5mm) Package

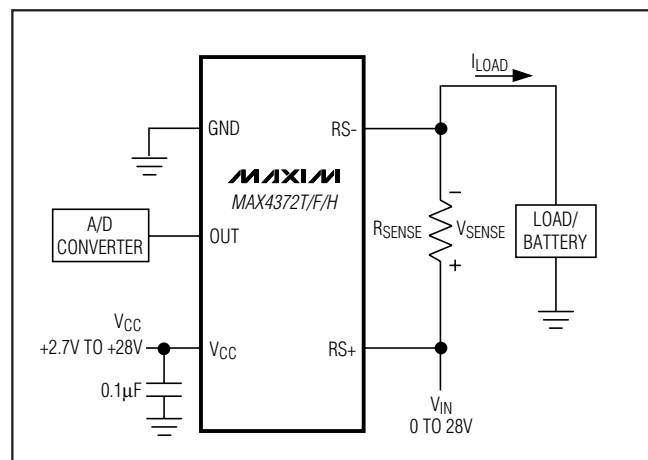
## Ordering Information

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	—
MAX4372TEBT-T	-40°C to +85°C	3 x 2 UCSP	ACX

**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.

Ordering Information continued at end of datasheet.

## Typical Operating Circuit



UCSP is a trademark of Maxim Integrated Products, Inc.



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## 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
3 x 2 UCSP (derate 3.4mW/°C above +70°C)	273.2mW

Operating Temperature Range	-40°C to +85°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (soldering, 10s)	+300°C
Bump Temperature (soldering)	
Infrared (15s)	+200°C
Vapor Phase (20s)	+215°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			
Input Offset Voltage (Note 5)	V <sub>OS</sub>	T <sub>A</sub> = +25°C V <sub>CC</sub> = V <sub>RS+</sub> = 12V	MAX4372_ESA		0.3	±0.8	mV	
			MAX4372_EUK, _EBT		0.3	±1.3		
		T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub> V <sub>CC</sub> = V <sub>RS+</sub> = 12V	MAX4372_ESA					±1.1
			MAX4372_EUK, _EBT					±1.9
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 7)			±0.18	±3	%	
Total OUT Voltage Error (Note 6)		V <sub>SENSE</sub> = 100mV, V <sub>CC</sub> = 12V, V <sub>RS+</sub> = 12V (Note 7)				±6	%	
		V <sub>SENSE</sub> = 100mV, V <sub>CC</sub> = 28V, V <sub>RS+</sub> = 28V (Note 7)			±0.15	±7		
		V <sub>SENSE</sub> = 100mV, V <sub>CC</sub> = 12V, V <sub>RS+</sub> = 0.1V (Note 7)			±1	±28		
		V <sub>SENSE</sub> = 6.25mV, V <sub>CC</sub> = 12V, V <sub>RS+</sub> = 12V (Note 8)			±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, UCSP/SOT23, Micropower, High-Side Current-Sense Amplifier with Voltage Output

## 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	$V_{RS+} = 12V$ , $V_{CC} = 12V$ , $C_{LOAD} = 10pF$	$V_{SENSE} = 20mV$ , gain = 20V/V		275		kHz
			$V_{SENSE} = 20mV$ , gain = 50V/V		200		
			$V_{SENSE} = 20mV$ , 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 9)		$V_{CC} = 12V$ , $V_{RS+} = 12V$ , $C_{LOAD} = 10pF$			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:**  $V_{OS}$  is extrapolated from the gain accuracy tests.

**Note 6:** Total OUT voltage error is the sum of gain and offset voltage errors.

**Note 7:** 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 8:** 6.25mV = 1/16 of 100mV full-scale voltage (C/16).

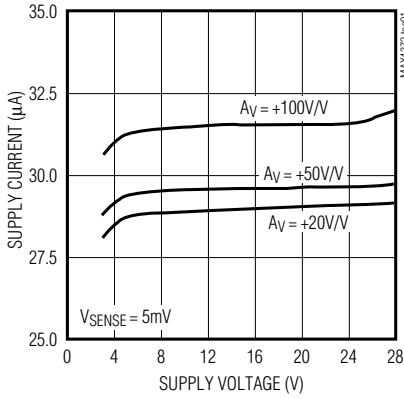
**Note 9:** The device will not reverse phase when overdriven.

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

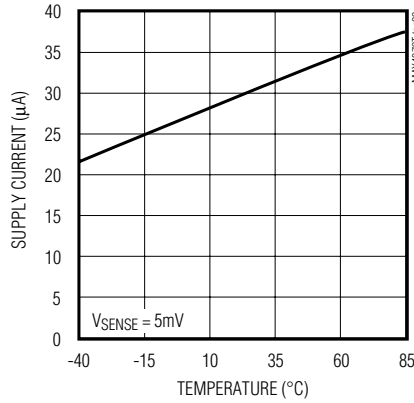
## Typical Operating Characteristics

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

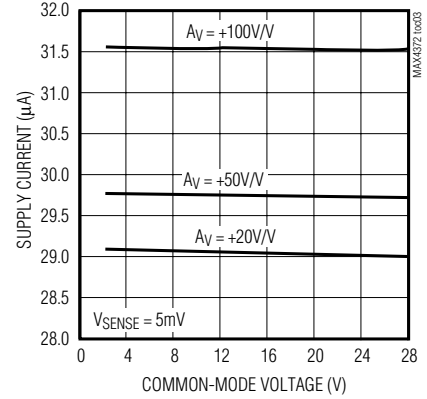
**SUPPLY CURRENT vs. SUPPLY VOLTAGE**



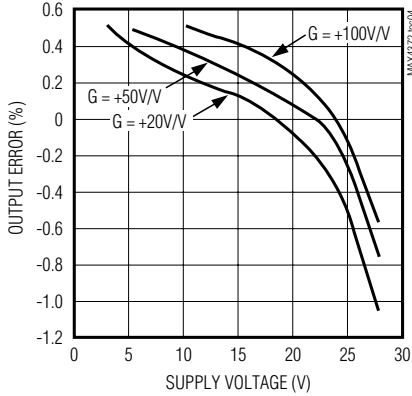
**SUPPLY CURRENT vs. TEMPERATURE**



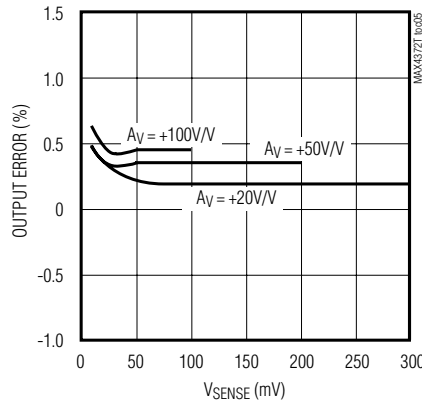
**SUPPLY CURRENT vs. COMMON-MODE VOLTAGE**



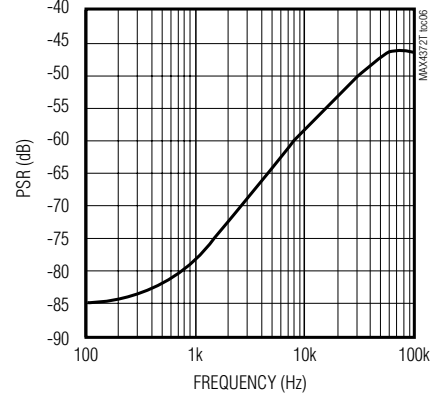
**TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE**



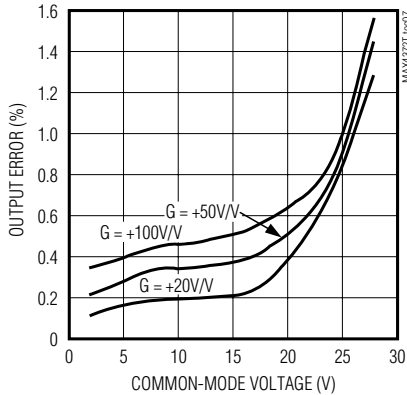
**TOTAL OUTPUT ERROR vs. VSENSE**



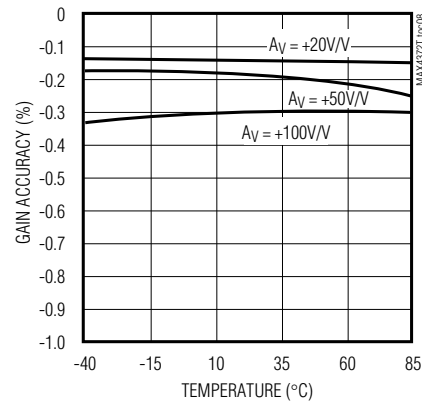
**POWER-SUPPLY REJECTION vs. FREQUENCY**



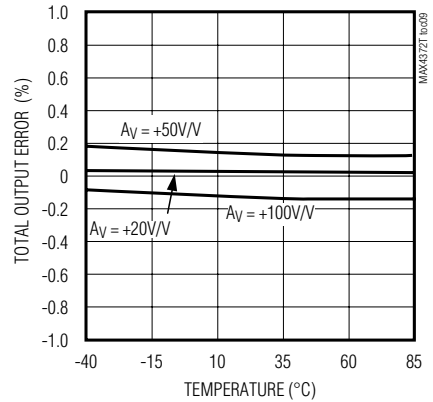
**TOTAL OUTPUT ERROR vs. COMMON-MODE VOLTAGE**



**GAIN ACCURACY vs. TEMPERATURE**



**TOTAL OUTPUT ERROR vs. TEMPERATURE**

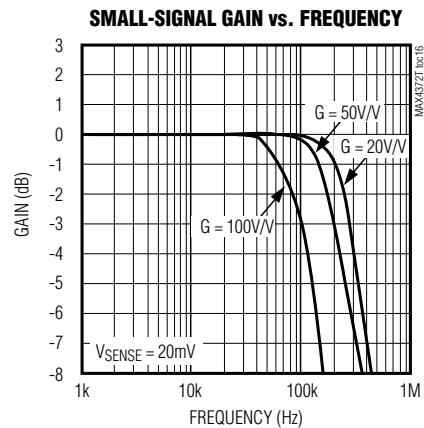
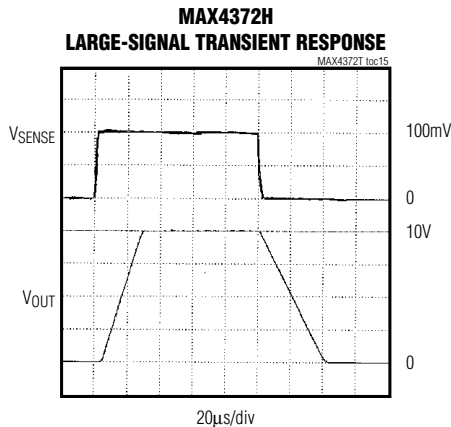
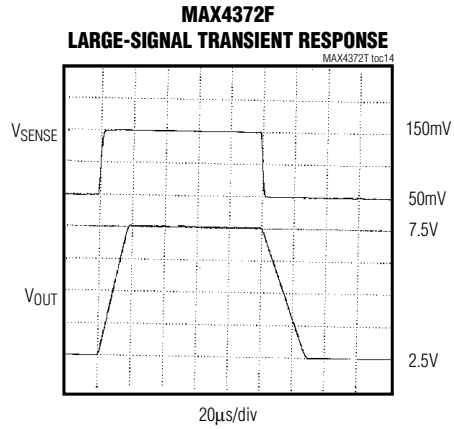
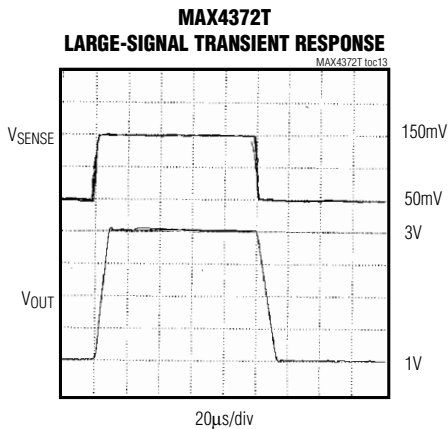
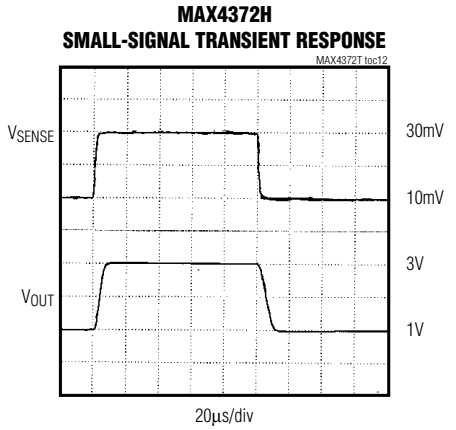
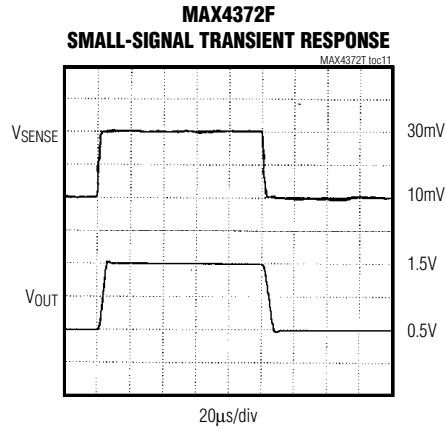
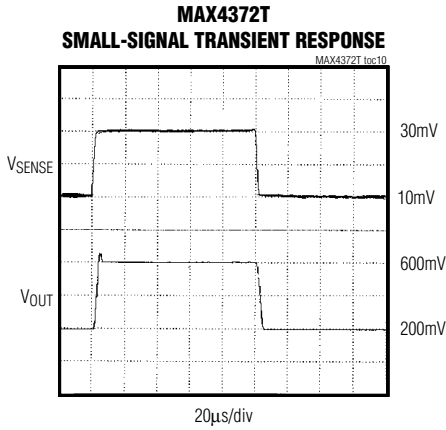


# Low-Cost, UCSP/SOT23, Micropower, High-Side Current-Sense Amplifier with Voltage Output

MAX4372T/F/H

## Typical Operating Characteristics (continued)

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



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

## Pin Description

PIN			NAME	FUNCTION
SOT23	SO	UCSP		
1	3	A2	GND	Ground
2	4	A3	OUT	Output Voltage. $V_{OUT}$ is proportional to the magnitude of $V_{SENSE}$ ( $V_{RS+} - V_{RS-}$ ).
3	1	A1	$V_{CC}$	Supply Voltage. Use at least a 0.1 $\mu$ F capacitor to decouple $V_{CC}$ from fast transients.
4	8	B1	RS+	Power Connection to the External Sense Resistor
5	6	B3	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.

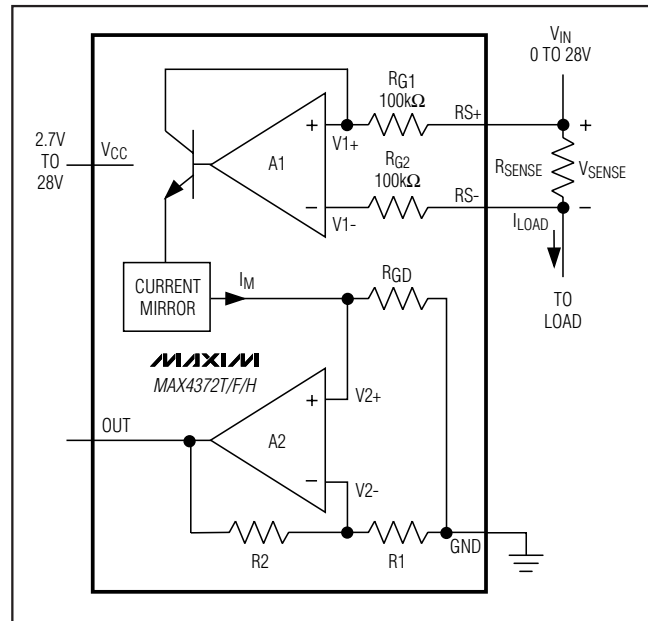


Figure 1. Functional Diagram

### Choosing $R_{SENSE}$

Given the gain and maximum load current, select  $R_{SENSE}$  such that  $V_{OUT}$  does not exceed  $V_{CC} - 0.25V$  or 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, UCSP/SOT23, Micropower, High-Side Current-Sense Amplifier with Voltage Output

**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 $V_{SENSE} = 100mV$ ), $V_{OUT}$ (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

### 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.

### UCSP Applications Information

For the latest application details on UCSP construction, dimensions, tape carrier information, printed circuit board techniques, bump-pad layout, and recommended reflow temperature profile, as well as the latest information on reliability testing results, go to the Maxim's website at [www.maxim-ic.com/ucsp](http://www.maxim-ic.com/ucsp) to find the Application Note: UCSP—A Wafer-Level Chip-Scale Package.

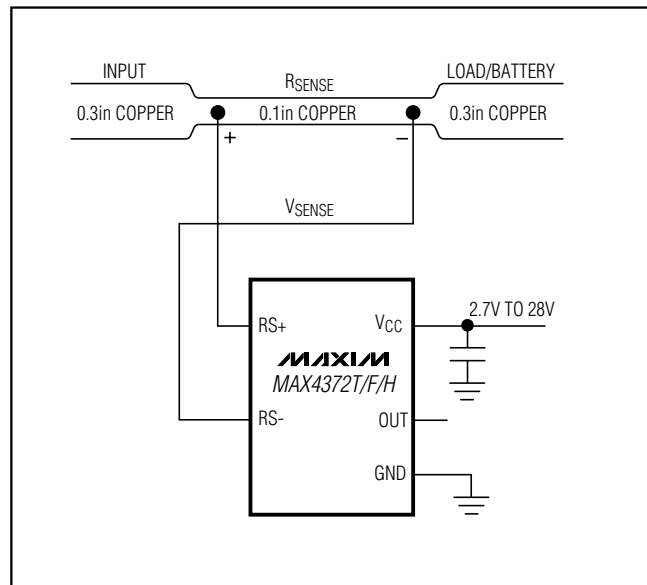


Figure 2. Connections Showing Use of PC Board

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

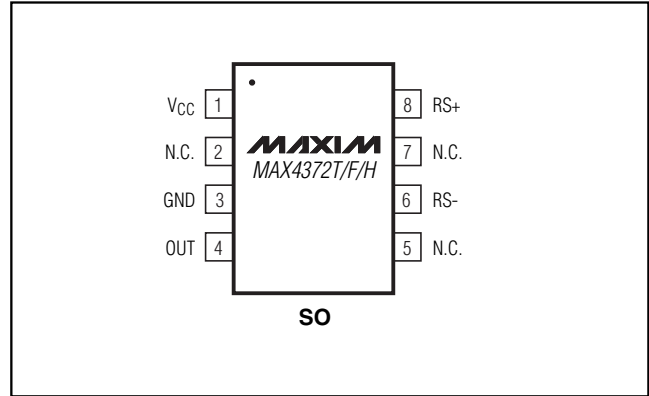
## Ordering Information (continued)

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX4372FEUK-T	-40°C to +85°C	5 SOT23-5	ADIV
MAX4372FESA	-40°C to +85°C	8 SO	—
MAX4372FEBT-T	-40°C to +85°C	3 x 2 UCSP	ACY
MAX4372HEUK-T	-40°C to +85°C	5 SOT23-5	ADIW
MAX4372HESA	-40°C to +85°C	8 SO	—
MAX4372HEBT-T	-40°C to +85°C	3 x 2 UCSP	ACZ

## Chip Information

TRANSISTOR COUNT: 225  
 PROCESS: BiCMOS

## Pin Configurations (continued)



## 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](http://www.maxim-ic.com/packages).)

**TOP VIEW**

**BOTTOM VIEW**

COMMON DIMENSIONS		VARIABLE DIMENSIONS		DEPOPULATED SOLDER BALLS	
		D	E		
A	0.62±0.05-0.08	B6-1	1.00±0.05	1.52±0.05	NONE
A1	0.29±0.02	B6-2	1.00±0.05	1.52±0.05	B2
A2	0.33 REF.	B6-3	1.05±0.05	1.57±0.05	NONE
b	∅0.35±0.03	B6-4	1.05±0.05	1.57±0.05	B2
D1	0.50 BASIC	B6-5	0.97±0.05	1.46±0.05	NONE
E1	1.00 BASIC	B6-6	1.16±0.05	1.57±0.05	NONE
e	0.50 BASIC				
SD	0.25 BASIC				
SE	0.00 BASIC				

**NOTES:**  
 1. ALL DIMENSIONS ARE IN MILLIMETERS.  
 2. PRODUCT MARKING: NUMBER OF CHARACTERS AND LINES VARY PER PRODUCT.

**SIDE VIEW**

PROPRIETARY INFORMATION  
 TITLE: PACKAGE OUTLINE, 3x2 UCSP  
 APPROVAL: [ ] DOCUMENT CONTROL NO. 21-0097 REV. G 1/1

Note: MAX4372\_EBT uses package code B6-2.



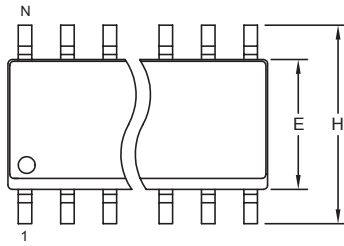
# Low-Cost, UCSP/SOT23, Micropower, High-Side Current-Sense Amplifier with Voltage Output

## Package Information (continued)

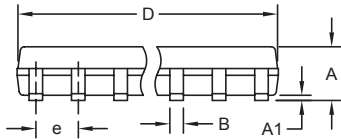
(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to [www.maxim-ic.com/packages](http://www.maxim-ic.com/packages).)

MAX4372T/F/H

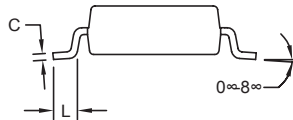
SOIC N EP5



TOP VIEW



FRONT VIEW



SIDE VIEW

DIM	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 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:

DIM	INCHES		MILLIMETERS		N	MS012
	MIN	MAX	MIN	MAX		
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

NOTES:

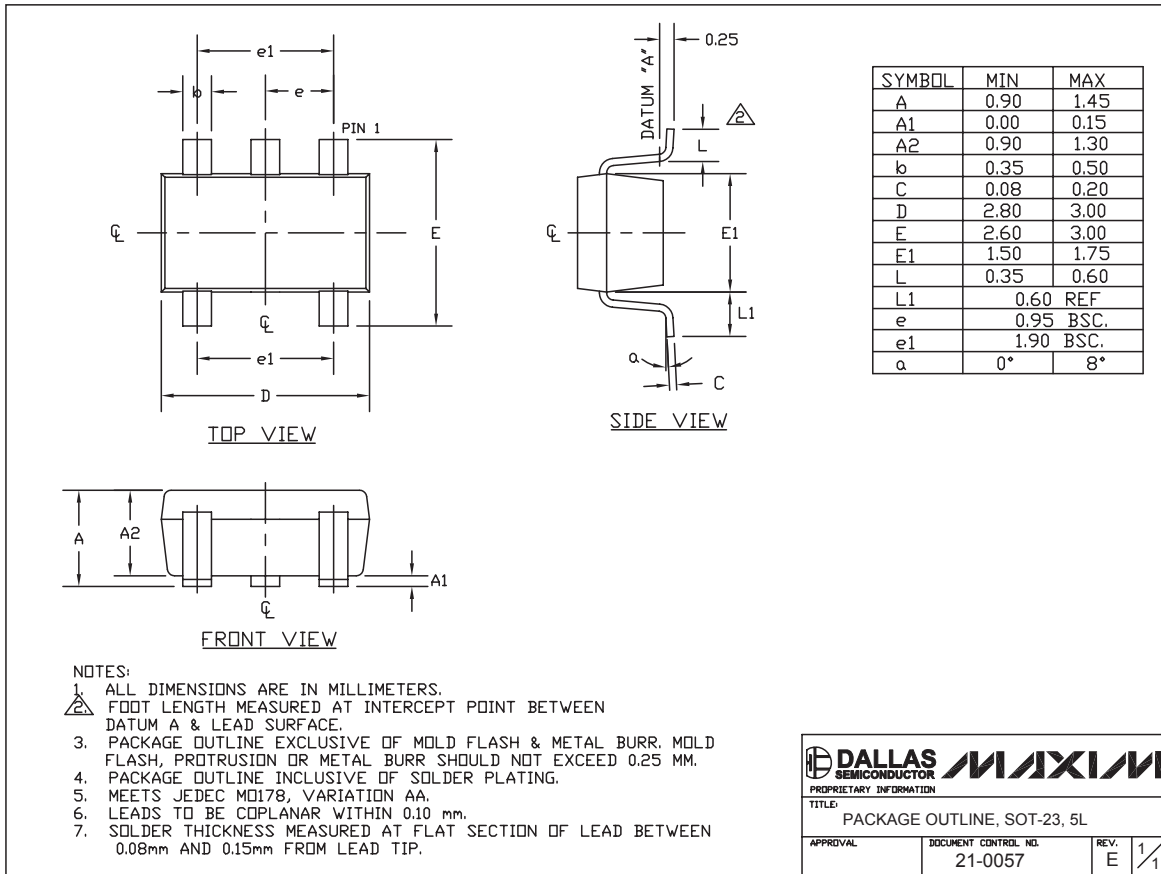
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED 0.15mm (.006").
3. LEADS TO BE COPLANAR WITHIN 0.10mm (.004").
4. CONTROLLING DIMENSION: MILLIMETERS.
5. MEETS JEDEC MS012.
6. N = NUMBER OF PINS.

<small>PROPRIETARY INFORMATION</small>	
<small>TITLE:</small> PACKAGE OUTLINE, .150" SOIC	
<small>APPROVAL</small>	<small>DOCUMENT CONTROL NO.</small> 21-0041
<small>REV.</small> B	<small>1</small> / 1

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

## 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](http://www.maxim-ic.com/packages).)



SOT-23 5L EFS

<small>PROPRIETARY INFORMATION</small>	
TITLE: PACKAGE OUTLINE, SOT-23, 5L	
APPROVAL:	DOCUMENT CONTROL NO. 21-0057
REV. E	1/1

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