## **General Description**

The MAX4372 low-cost, precision, high-side currentsense 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

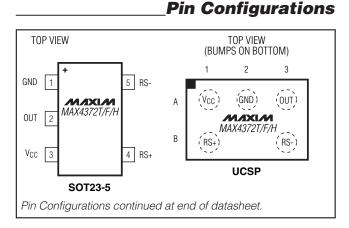
Notebook Computers

Portable/Battery-Powered Systems

Smart-Battery Packs/Chargers

Cell Phones

Precision-Current Sources



# M/IXI/M

#### \_Features

Low-Cost, Compact Current-Sense Solution

MXXM

- ♦ 30µA Supply Current
- ♦ 2.7V to 28V Operating Supply
- 0.18% Full-Scale Accuracy
- 0.3mV Input Offset Voltage
- ♦ Low 1.5Ω Output Impedance
- Three Gain Versions Available 20V/V (MAX4372T) 50V/V (MAX4372F) 100V/V (MAX4372H)
- High Accuracy +2V to +28V Common-Mode Range, Functional Down to 0V, Independent of Supply Voltage
- Available in a Space-Saving 5-Pin SOT23 Package and 3 x 2 UCSP™ (1mm x 1.5mm) Package

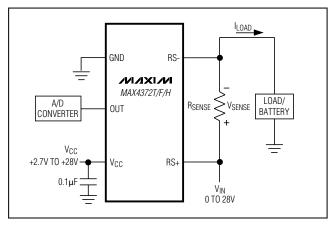
# **\_Ordering Information**

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX4372TEUK+T	-40°C to +85°C	5 SOT23-5	ADIU
MAX4372TESA+T	-40°C to +85°C	8 SO	_
MAX4372TEBT+T	-40°C to +85°C	3 x 2 UCSP	ACX

+Denotes a lead(Pb)-free/RoHS-compliant package. T = Tape and reel.

**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



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Maxim Integrated Products 1

For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

#### **ABSOLUTE MAXIMUM RATINGS**

V <sub>CC</sub> , RS+, RS- to GND	
Differential Input Voltage (V <sub>RS+</sub> - V <sub>RS-</sub> )	
Current into Any Pin	
Continuous Power Dissipation ( $T_A = +70^{\circ}C$ )	
5-Pin SOT23 (derate 3.9mW/°C above +70°C)	
8-Pin SO (derate 7.4mW/°C above +70°C)	588.2mW
3 x 2 UCSP (derate 3.4mW/°C above +70°C)	273.2mW

Operating Temperature Range	40°C to +85°C
Storage Temperature Range	
Lead Temperature (soldering, 10s)	+300°C
Soldering Temperature (reflow)	+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**

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

PARAMETER	SYMBOL	CONE	DITIONS	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	$V_{RS+} > 2V$			85		dB
Supply Current	lcc	V <sub>RS+</sub> > 2V, V <sub>SENSE</sub> =	5mV		30	60	μA
Leakage Current	I <sub>RS+</sub> , I <sub>RS-</sub>	$V_{\rm CC} = 0V, V_{\rm RS+} = 28V$	/		0.05	1.2	μA
	I <sub>RS+</sub>	$V_{RS+} > 2V$ $V_{RS+} \le 2V$		0 -25		1	
Input Bias Current	I <sub>RS-</sub>	$V_{RS+} \ge 2V$ $V_{RS+} > 2V$		0		2	μA
	-00-	$V_{RS+} \le 2V$		-50		2	
Full-Scale Sense Voltage	VSENSE	Gain = 20V/V or 50V/V			150		mV
(Note 4)	* SEINSE	Gain = 100V/V			100		
	Vos	$T_A = +25^{\circ}C$	MAX4372_ESA		0.3	±0.8	±0.8 ±1.3 mV
Input Offset Voltage		$V_{\rm CC} = V_{\rm RS+} = 12V$	MAX4372_EUK, _EBT		0.3	±1.3	
(Note 5)	.00	$T_A = T_{MIN}$ to $T_{MAX}$	MAX4372_ESA			±1.1	
		$V_{CC} = V_{RS+} = 12V$	MAX4372_EUK, _EBT			±1.9	
Full-Scale Accuracy (Note 5)		$V_{SENSE} = 100mV, V_{CO}$ $V_{RS+} = 12V, T_{A} = +25$	5		±0.18	±3	%
		$V_{\text{SENSE}} = 100 \text{mV}, V_{\text{CO}}$ $V_{\text{RS+}} = 12 \text{V} (\text{Note 7})$	c = 12V,			±6	
Total OUT Voltage Error (Note 6)		VSENSE = 100mV, VCC = 28V, VRS+ = 28V (Note 7)			±0.15	±7	0/
		$V_{\text{SENSE}} = 100 \text{mV}, V_{\text{CC}}$ $V_{\text{RS+}} = 0.1 \text{V} \text{ (Note 7)}$	<sub>C</sub> = 12V,		±1	±28	. %
		$V_{\text{SENSE}} = 6.25 \text{mV}, V_{\text{C}}$ $V_{\text{RS+}} = 12 \text{V} \text{ (Note 8)}$	C = 12V,		±0.15		

# **ELECTRICAL CHARACTERISTICS (continued)**

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

PARAMETER	SYMBOL	CON	NDITIONS	MIN	ТҮР	MAX	UNITS
OUT Low Voltage		$V_{CC} = 2.7V,$	I <sub>OUT</sub> = 10µA		2.6		100)/
(MAX4372T, MAX4372F)	V <sub>OL</sub>	VSENSE = -10mV VRS+ = 28V	I <sub>OUT</sub> = 100μA		9	65	mV
OUT Low Voltage		$V_{CC} = 2.7V,$	I <sub>OUT</sub> = 10µA		2.6		mV
(MAX4372H)	VOL	$V_{\rm RS+} = 12V$	$I_{OUT} = 100 \mu A$		9	65	
OUT High Voltage	V <sub>CC</sub> - V <sub>OH</sub>	$V_{RS+} = 28V, V_{CC} = 2000$ V <sub>SENSE</sub> = 250mV	2.7V, I <sub>OUT</sub> = -500µA,		0.1	0.25	V
			V <sub>SENSE</sub> = 20mV, gain = 20V/V		275		
-3dB Bandwidth	BW	Vol. VSENSE = -10mV VRS+ = 28V IOUT = 100µA   VOL VCC = 2.7V, VSENSE = -10mV VRS+ = 12V IOUT = 10µA   VOL VRS+ = 12V, VSENSE = 250mV IOUT = 10µA   V VRS+ = 12V, VSENSE = 250mV IOUT = 100µA   BW VRS+ = 28V, VCC = 2.7V, IOUT = -500µA, VSENSE = 250mV VSENSE = 20mV, gain = 20V/V   BW VRS+ = 12V, VCC = 12V, CLOAD = 10pF VSENSE = 20mV, gain = 50V/V   VSENSE = 20mV, Gain = 100V/V VSENSE = 20mV, gain = 100V/V   VSENSE = 20mV to 100mV, VRS+ = 12V TA = +25°C   MAX4372H TA = -40°C to +85°C   Gain = 20V/V, VCC = 12V, VRS+ = 12V, CLOAD = 10pF VSENSE = 6.25mV to 100mV   Gain = 20V/V, VRS+ = 12V, CLOAD = 10pF VSENSE = 100mV to 6.25mV   No sustained oscillations VSENSE = 100mV to 6.25mV		200		kHz	
		$C_{LOAD} = 10 pF$			110		
			V <sub>SENSE</sub> = 6.25mV	50		1	
		MAX4372T 2		20			
Gain		MAX4372F			50		V/V
		MAX4372H			100		
Gain Accuracy		V <sub>SENSE</sub> = 20mV	$T_A = +25^{\circ}C$		±0.25	±2.5	%
Gain Accuracy		to 100mV,V <sub>RS+</sub> =12V	$T_A = -40^{\circ}C \text{ to } +85^{\circ}C$			±5.5	/0
OUT Settling Time to 1% of					20		
Final Value		_			20		μs
Capacitive-Load Stability		No sustained oscilla	tions		1000		pF
OUT Output Resistance	Rout	V <sub>SENSE</sub> = 100mV			1.5		Ω
Power-Supply Rejection	PSR	$V_{OUT} = 2V, V_{RS+} > 2$	2V	75	85		dB
Power-Up Time to 1% of Final Value					0.5		ms
Saturation Recovery Time (Note 9)		$V_{CC} = 12V, V_{RS+} = 12V$	12V, C <sub>LOAD</sub> = 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: Vos is extrapolated from the gain accuracy tests.

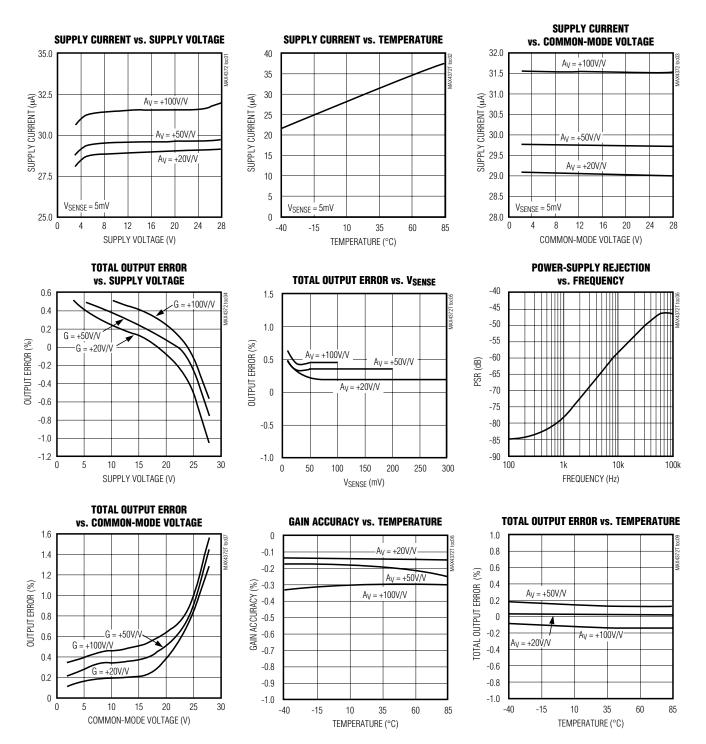
Note 6: Total OUT voltage error is the sum of gain and offset voltage errors.

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.

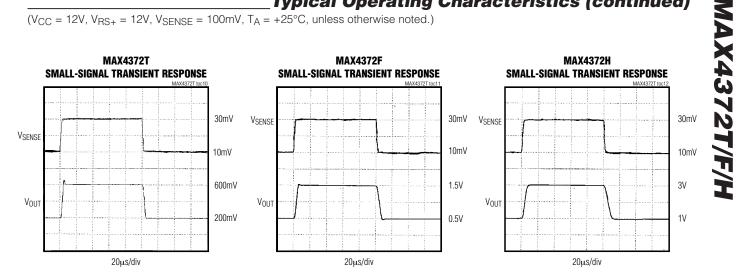
**Typical Operating Characteristics** (V<sub>CC</sub> = 12V, V<sub>RS+</sub> = 12V, V<sub>SENSE</sub> = 100mV, T<sub>A</sub> = +25°C, unless otherwise noted.)



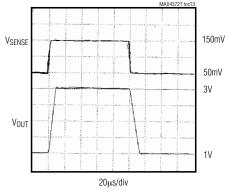
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## \_Typical Operating Characteristics (continued)

(V<sub>CC</sub> = 12V, V<sub>RS+</sub> = 12V, V<sub>SENSE</sub> = 100mV,  $T_A$  = +25°C, unless otherwise noted.)



MAX4372T LARGE-SIGNAL TRANSIENT RESPONSE

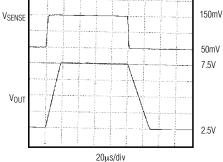


**MAX4372H** LARGE-SIGNAL TRANSIENT RESPONSE 100mV VSENSE 0 10V VOUT

20µs/div

0

MAX4372F LARGE-SIGNAL TRANSIENT RESPONSE



**SMALL-SIGNAL GAIN vs. FREQUENCY** 3 2 1 G 50V/\ 0 G -1 -2 -3 G = 100V/V -4 -5 -6 -7 V<sub>SENSE</sub> = 20mV -8 100k 1k 10k 1M FREQUENCY (Hz)

GAIN (dB)

## Pin/Bump Description

Р	IN	BUMP	NAME	FUNCTION	
SOT23	SO	UCSP		FONCTION	
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	Vcc	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<sub>CC</sub>).

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<sub>IN</sub> - V<sub>SENSE</sub>. A1 forces its positive terminal to match its negative terminal; therefore, the voltage across R<sub>G1</sub> (V<sub>IN</sub> - V1-) equals V<sub>SENSE</sub>. This creates a current to flow through R<sub>G1</sub> equal to V<sub>SENSE</sub> / R<sub>G1</sub>. 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:

V2+ = RGD  $\beta$  • VSENSE / RG1

R1 and R2 set the closed-loop gain for A2, which amplifies V2+, 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.

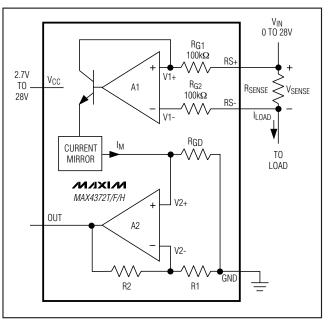


Figure 1. Functional Diagram

#### **Choosing RSENSE**

Given the gain and maximum load current, select R<sub>SENSE</sub> 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<sub>SENSE</sub>. 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<sub>SENSE</sub> is able to dissipate its own I<sup>2</sup>R 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.



FULL-SCALE LOAD CURRENT, I <sub>LOAD</sub> (A)	CURRENT-SENSE RESISTOR, RSENSE (mΩ)	GAIN (V/V)	FULL-SCALE OUTPUT VOLTAGE (FULL-SCALE VSENSE = 100mV), VOUT (V)
		20	2.0
0.1	1000	50	5.0
		100	10.0
		20	2.0
1	100	50	5.0
		100	10.0
		20	2.0
5	20	50	5.0
		100	10.0
		20	2.0
10	10	50	5.0
		100	10.0

#### **Table 1. Recommended Component Values**

#### Using a PC Board Trace as RSENSE

If the cost of RSENSE 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  $0.4\%/^{\circ}C$ ), 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<sub>SENSE</sub> of  $5m\Omega$ ) creates a full-scale V<sub>SENSE</sub> of 50mV that yields a maximum V<sub>OUT</sub> of 1V. R<sub>SENSE</sub>, 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 to find the Application Note: UCSP—A Wafer-Level Chip-Scale Package.

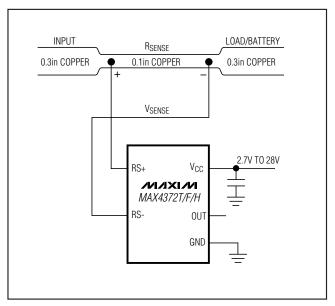


Figure 2. Connections Showing Use of PC Board

## **Ordering Information (continued)**

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX4372FEUK+T	-40°C to +85°C	5 SOT23-5	ADIV
MAX4372FESA+T	-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+T	-40°C to +85°C	8 SO	—
MAX4372HEBT+T	-40°C to +85°C	3 x 2 UCSP	ACZ
+Denotes a lead(Pb	)-free/RoHS-com	pliant package.	

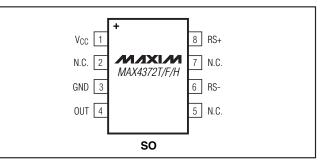
Penotes a lead(Pb)-free/RoHS-compliant pack

T = Tape and reel.

## **Chip Information**

PROCESS: BICMOS

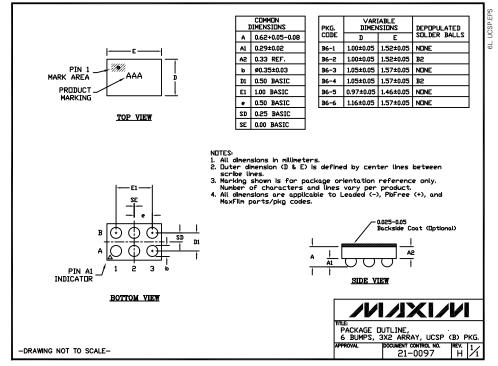
## \_Pin Configurations (continued)



## **Package Information**

For the latest package outline information and land patterns, go to <u>www.maxim-ic.com/packages</u>. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

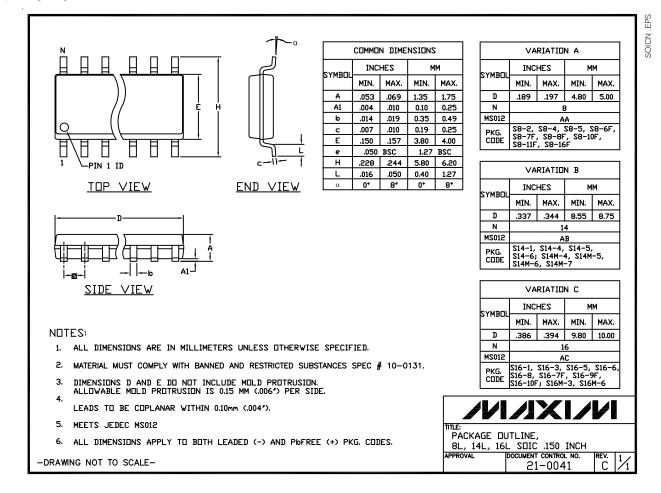
PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
5 SOT23	U5+1	<u>21-0057</u>	<u>90-0174</u>
8 SO	S8+2	<u>21-0041</u>	<u>90-0096</u>
5 UCSP	B6+2	<u>21-0097</u>	



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

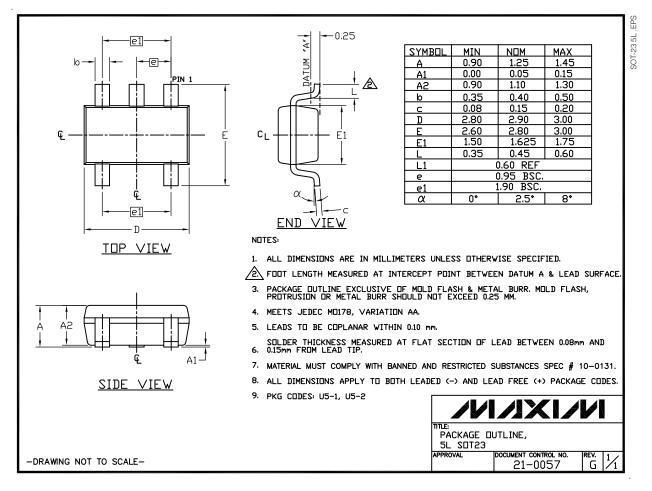
# Package Information (continued)

For the latest package outline information and land patterns, go to <u>www.maxim-ic.com/packages</u>. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.



#### Package Information (continued)

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## **Revision History**

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
4	7/09	Updated feature in accordance with actual performance of the product	1
5	5/11	Updated VRST conditions to synchronize with tested material and added lead-free designation	1, 2, 3, 8

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