19-1781; Rev 4; 4/09

Single/Dual/Quad, High-Side Current-Sense Amplifiers with Internal Gain

MAX4376/MAX4377/MAX4378

General Description

The MAX4376/MAX4377/MAX4378 single, dual, and quad precision high-side current-sense amplifiers are available in space-saving packages. They feature buffered voltage outputs that eliminate the need for gain-setting resistors and are ideal for today's notebook computers, cell phones, and other systems where current monitoring is critical. These precision devices are offered in three fixed-gain versions of 20, 50, and 100:

GAIN	SUFFIX
20	T
50	F
100	H

For example, MAX4376TAUK is a single high-side amplifier with a gain of 20.

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 pack in deep discharge.

The full-scale current reading can be set by choosing the appropriate voltage gain and external-sense resistor. This capability offers a high level of integration and flexibility, resulting in a simple and compact current-sense solution.

The MAX4376/MAX4377/MAX4378 operate over a supply voltage range of +3V to +28V, draw 1mA of supply current per amplifier, and operate over the full automotive temperature range of -40°C to +125°C. These devices have a wide bandwidth of 2MHz, making them suitable for use inside battery-charger control loops. The buffered outputs drive up to 2mA of output current into a ground-referenced load.

The MAX4376 is available in a tiny 5-pin SOT23 package. The MAX4377/MAX4378 are available in space-saving 8-pin µMAX and 14-pin TSSOP packages, respectively.

Applications

- Notebook Computers
- Current-Limited Power Supplies
- Fuel Gauges in PC
- General-System/Board-Level Current Monitoring
- Battery Chargers
- Portable/Battery-Powered Systems
- Cell Phones
- Smart Battery Packages
- Automotive Current Detect
- Power Management Systems
- PA Bias Control

Features

- ♦ Low-Cost, Single/Dual/Quad, High-Side Current-Sense Amplifiers
- ♦ ±0.5% Typical Full-Scale Accuracy
- ♦ +3V to +28V Supply Operation
- ♦ Adjustable Current-Sense Capability with External Sense Resistor
- ♦ Buffered Output Voltage with 2mA Drive
- ♦ 1mA (typ) Supply Current
- ♦ 2.0MHz Bandwidth (Gain = +20V/V)
- ♦ Automotive Temperature Range (-40°C to +125°C)
- ♦ Full 0 to 28V Common-Mode Range, Independent of Supply Voltage
- ♦ Three Gain Versions Available
  - +20V/V (MAX437_T)
  - +50V/V (MAX437_F)
  - +100V/V (MAX437_H)
- ♦ Available in Space-Saving 5-Pin SOT23 (Single), 8-Pin µMAX (Dual), and 14-Pin TSSOP (Quad)

Ordering Information

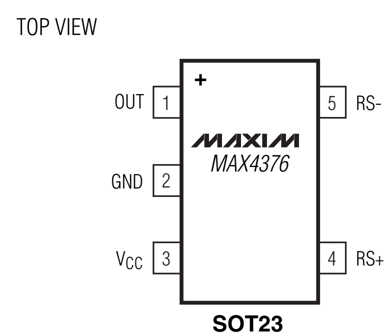
PART	GAIN (+V/V)	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX4376TAUK+T	20	-40°C to +125°C	5 SOT23	ADOG
MAX4376FAUK+T	50	-40°C to +125°C	5 SOT23	ADOH
MAX4376HAUK+T	100	-40°C to +125°C	5 SOT23	ADOI
MAX4376HAUK/V+T	100	-40°C to +125°C	5 SOT23	AFGO
MAX4376TASA+	20	-40°C to +125°C	8 SO	—
MAX4376FASA+	50	-40°C to +125°C	8 SO	—

Ordering Information continued at end of data sheet.

+Denotes a lead(Pb)-free/RoHS-compliant package.

T = Tape and reel.

Pin Configurations



Pin Configurations continued at end of data sheet.

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.

Single/Dual/Quad, High-Side Current-Sense Amplifiers with Internal Gain

ABSOLUTE MAXIMUM RATINGS

V_{CC}, RS+, RS- to GND ....-0.3V to +30V
OUT to GND ....-0.3V to (V_{CC} + 0.3V)
Differential Input Voltage (V_{RS+} - V_{RS-})................................±8V
Output Short Circuit to V_{CC}.......................................Continuous
Output Short Circuit to GND 1s
Current into Any Pin...±20mA
Continuous Power Dissipation (T_A = +70°C)
  5-Pin SOT23 (derate 7.1mW/°C above +70°C)...........571mW
  8-Pin µMAX (derate 4.5mW/°C above +70°C)............362mW
  8-Pin SO (derate 5.88mW/°C above +70°C)...............471mW
  14-Pin SO (derate 8.33mW/°C above +70°C).............667mW
  14-Pin TSSOP (derate 9.1mW/°C above +70°C) 727mW
Operating Temperature Range ....-40°C to +125°C
Junction Temperature ....+150°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_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, V_{CC} = +3.0V to +28V, R_L = ∞, T_A = T_{MIN} to T_{MAX}, 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_{CM}	Guaranteed by total OUT voltage error test		0		28	V
Common-Mode Rejection	CMR	2V ≤ V_{RS+} ≤ 28V, V_{SENSE} = 100mV			90		dB
Supply Current per Amplifier	I_{CC}	V_{SENSE} = 5mV, V_{RS+} > 2.0V, V_{CC} = 12V			1	2.2	mA
Leakage Current	I_{RS+}, I_{RS-}	V_{CC} = 0V, V_{RS+} = 28V				8	µA
Input Bias Current	I_{RS+}	V_{RS+} > 2.0V		0		60	µA
		V_{RS+} ≤ 2.0V		-400		60	
	I_{RS-}	V_{RS+} > 2.0V		0		120	
		V_{RS+} ≤ 2.0V		-800		120	
Full-Scale Sense Voltage	V_{SENSE}				150		mV
Total OUT Voltage Error (Note 2)		I_{OUT} ≤ 2mA	V_{SENSE} = 100mV, V_{CC} = 12V, V_{RS+} = 12V			±6.75	%
			V_{SENSE} = 100mV, V_{CC} = 12V, T_A = +25°C		±0.5	±3.25	
			V_{SENSE} = 100mV, V_{CC} = 28V, V_{RS+} = 28V			±11	
			V_{SENSE} = 100mV, V_{CC} = 28V, V_{RS+} = 28V, T_A = +25°C		±0.5	±5	
			V_{SENSE} = 100mV, V_{CC} = 12V, V_{RS+} = 0.1V		±9	±32	
			V_{SENSE} = 6.25mV, V_{CC} = 12V, V_{RS+} = 12V (Note 3)		±7		
OUT High Voltage (Note 4)	(V_{CC} - V_{OUT})	V_{CC} = 3V, I_{OUT} = 2mA			0.9	1.2	V
OUT Low Voltage	V_{OL}	I_{OUT} = 200µA, V_{CC} = V_{RS+} = 12V, V_{SENSE} = 0V, T_A = +25°C			25	40	mV

ELECTRICAL CHARACTERISTICS (continued)

(V_{RS+} = 0 to 28V, V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, V_{CC} = +3.0V to +28V, R_L = ∞, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = 25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Bandwidth	BW	V_{CC} = 12V, V_{RS+} = 12V, C_{LOAD} = 15pF	V_{SENSE} = 100mV (gain = +20V/V)		2		MHz
			V_{SENSE} = 100mV (gain = +50V/V)		1.7		
			V_{SENSE} = 100mV (gain = +100V/V)		1.2		
			V_{SENSE} = 6.25mV (Note 3)		0.5		
Slew Rate	SR	V_{SENSE} = 20mV to 100mV, C_{LOAD} = 15pF			10		V/µs
Gain	A_V	MAX437_T			+20		V/V
		MAX437_F			+50		
		MAX437_H			+100		
Gain Accuracy	ΔA_V	V_{SENSE} = 10mV to 150mV, V_{CC} = 12V, I_{OUT} = 2mA, gain = 20 and 50	T_A = T_{MIN} to T_{MAX}			±5.5	%
			T_A = +25°C		±0.5	±2.5	
		V_{SENSE} = 10mV to 150mV, V_{CC} = 20V, I_{OUT} = 2mA, gain = 100	T_A = T_{MIN} to T_{MAX}			5.5	
			T_A = +25°C		±0.5	±2.5	
OUT Setting Time to 1% of Final Value		V_{CC} = 12V, V_{RS+} = 12V, C_{LOAD} = 15pF	V_{SENSE} = 6.25mV to 100mV		400		ns
			V_{SENSE} = 100mV to 6.25mV		800		
Maximum Capacitive Load	C_{LOAD}	No sustained oscillation			1000		pF
Output Resistance	R_{OUT}	V_{SENSE} = 100mV			5		Ω
Power-Supply Rejection	PSR	V_{RS+} > 2V, V_{OUT} = 1.6V, V_{CC} = 3V to 28V		66	90		dB
Power-Up Time to 1% of Final Value		V_{SENSE} = 100mV, C_{LOAD} = 15pF			2		µs
Saturation Recovery Time to 1% of Final Value		V_{CC} = 12V, V_{RS+} = 12V, C_{LOAD} = 15pF, V_{SENSE} = 100mV			1		µs
Reverse Recovery Time to 1% of Final Value		V_{CC} = 12V, $V_{RS\_}$ = 12V, C_{LOAD} = 15pF, V_{SENSE} = -100mV to +100mV			1		µs

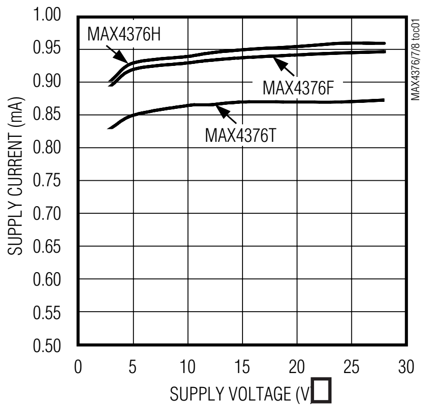
Note 1: All devices are 100% production tested at T_A = +25°C. All temperature limits are guaranteed by design.
Note 2: Total OUT Voltage Error is the sum of gain and offset errors.
Note 3: 6.25mV = 1/16 of 100mV full-scale sense voltage.
Note 4: V_{SENSE} such that V_{OUT} is in saturation.

Single/Dual/Quad, High-Side Current-Sense Amplifiers with Internal Gain

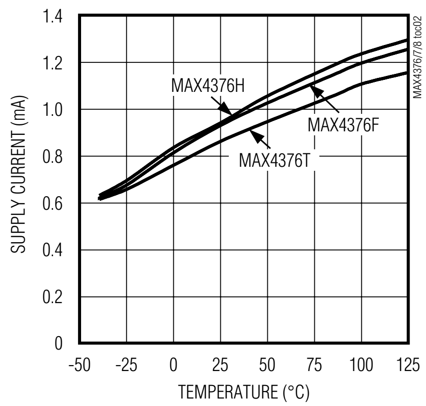
Typical Operating Characteristics

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

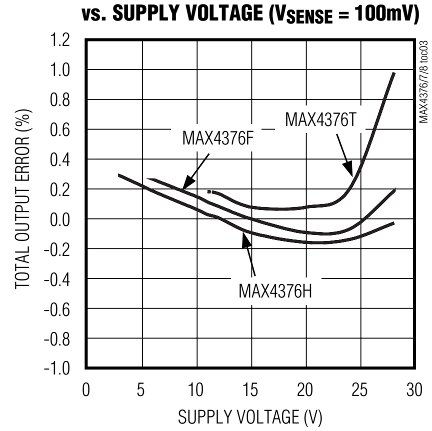
SUPPLY CURRENT (PER AMPLIFIER) vs. SUPPLY VOLTAGE



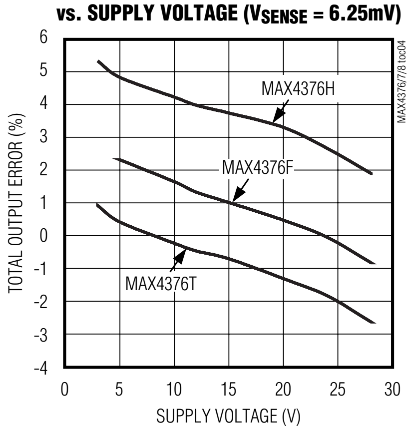
SUPPLY CURRENT (PER AMPLIFIER) vs. TEMPERATURE



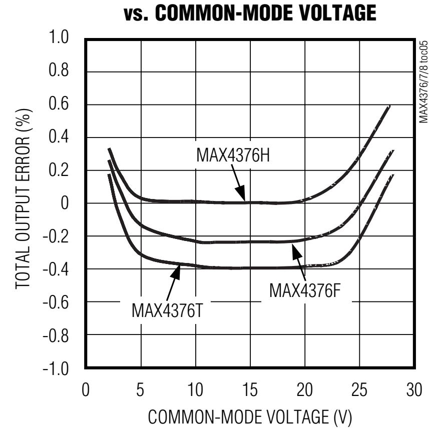
TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE (V_{SENSE} = 100mV)



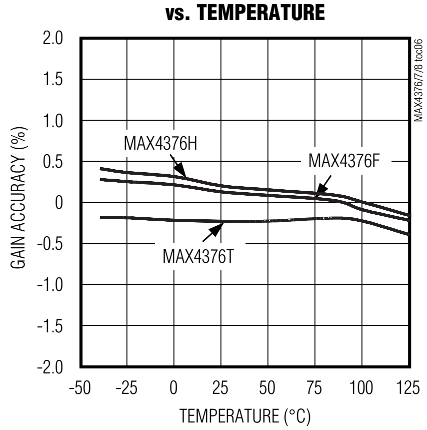
TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE (V_{SENSE} = 6.25mV)



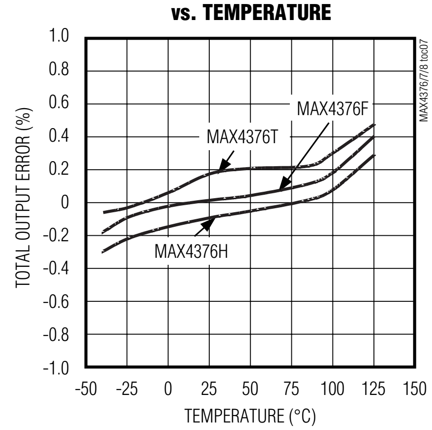
TOTAL OUTPUT ERROR vs. COMMON-MODE VOLTAGE



GAIN ACCURACY vs. TEMPERATURE



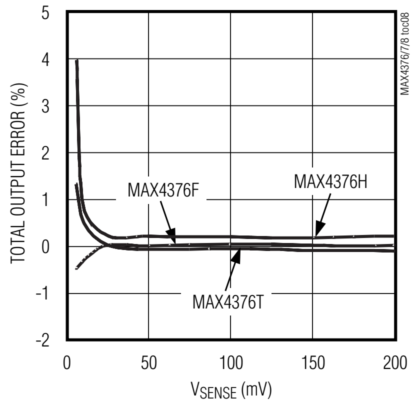
TOTAL OUTPUT ERROR vs. TEMPERATURE



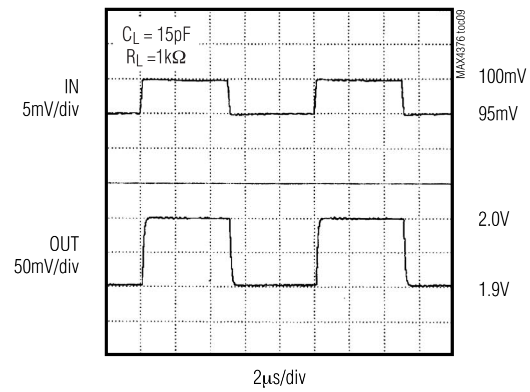
Typical Operating Characteristics (continued)

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

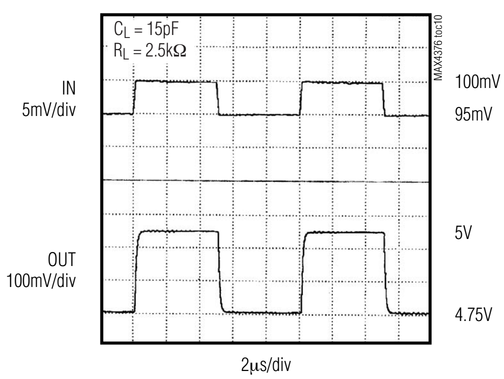
TOTAL OUTPUT ERROR vs. FULL-SCALE SENSE VOLTAGE



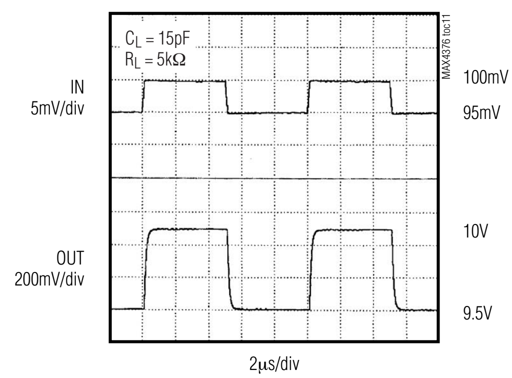
MAX4376T SMALL-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 95mV TO 100mV)



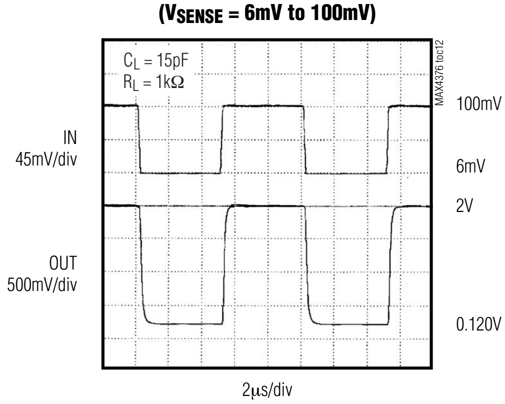
MAX4376F SMALL-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 95mV TO 100mV)



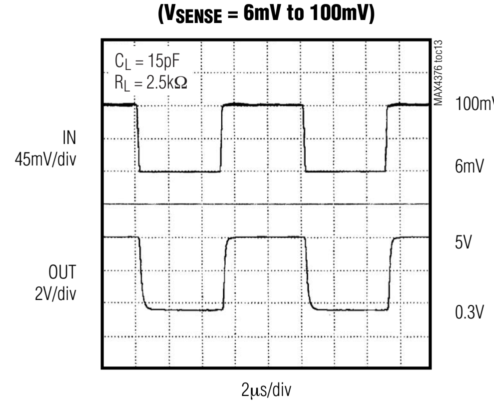
MAX4376H SMALL-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 95mV to 100mV)



MAX4376T LARGE-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 6mV to 100mV)



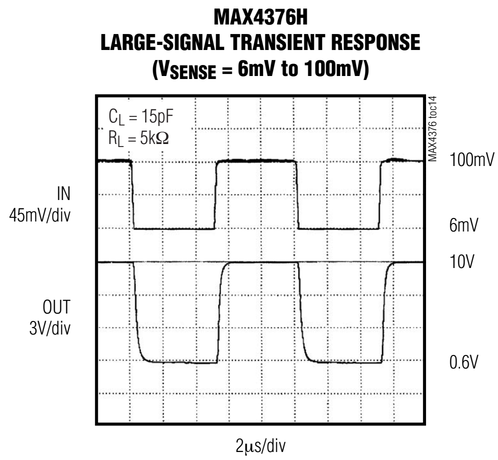
MAX4376F LARGE-SIGNAL TRANSIENT RESPONSE (V_{SENSE} = 6mV to 100mV)

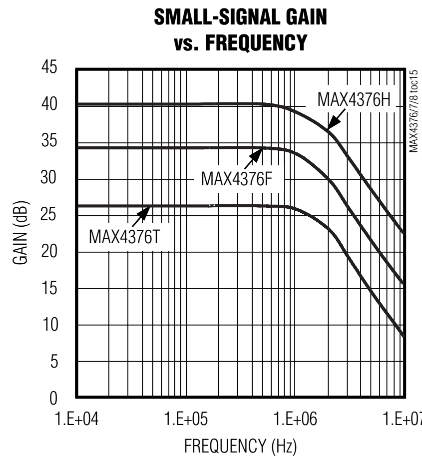


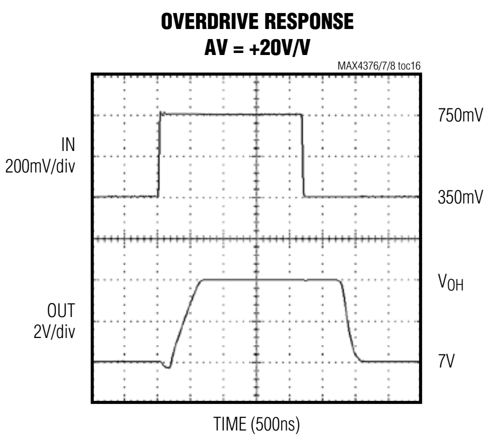
Single/Dual/Quad, High-Side Current-Sense Amplifiers with Internal Gain

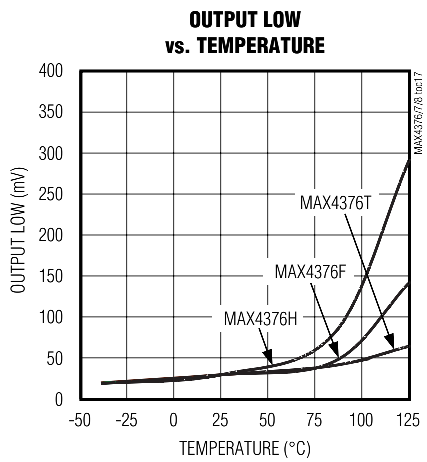
Typical Operating Characteristics (continued)

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









Pin Description

PIN				NAME	FUNCTION
MAX4376	MAX4376	MAX4377	MAX4378		
SOT23-5	SO-8	µMAX-8/ SO-8	SO-14/ TSSOP-14		
1	4	1, 7	1, 7, 8, 14	OUT, OUT_	Output Voltage. $V_{OUT\_}$ is proportional to the magnitude of the sense voltage (V_{RS+} - V_{RS-}). $V_{OUT\_}$ is approximately zero when $V_{RS\ -}$ > $V_{RS\ -\ +}$ (no phase reversal).
2	3	4	11	GND	Ground
3	1	8	4	V_{CC}	Supply Voltage
4	8	3, 5	3, 5, 10, 12	RS+, RS_+	Power connection to the external sense resistor
5	6	2, 6	2, 6, 9, 13	RS-, RS_-	Load-side connection to the external sense resistor
—	2, 5, 7	—	—	N.C.	No Connection. Not internally connected.

Detailed Description

The MAX4376/MAX4377/MAX4378 high-side current-sense amplifiers feature 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 MAX4376/MAX4377/MAX4378 operate 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} = β x I_{RG1}. Solving I_{RGD} = β x (I_{LOAD})(R_{SENSE})/RG1. Therefore:

$$V_{OUT} = \beta \times (RGD/RG1)(R_{SENSE} \times I_{LOAD}) \times \text{amp gain}$$

where amp gain is 2, 5, or 10.

The part's gain equals (β x RGD / RG1) x amp gain.

Therefore:

$$V_{OUT} = (GAIN)(R_{SENSE})(I_{LOAD})$$

where GAIN = 20 for MAX437_T.

GAIN = 50 for MAX437_F.

GAIN = 100 for MAX437_H.

Set the full-scale output range by selecting R_{SENSE} and the appropriate gain version of the MAX4376/MAX4377/MAX4378.

Applications Information

Recommended Component Values

The MAX4376/MAX4377/MAX4378 sense a wide variety of currents with different sense resistor values. Table 1 lists common resistor values for typical operation of the MAX4376/MAX4377/MAX4378.

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.

Bidirectional Current-Sense Amplifier

Systems such as laptop computers and other devices that have internal charge circuitry require a precise bidirectional current-sense amplifier to monitor accurately the battery's current regardless of polarity. Figure 2 shows the MAX4377 used as a bidirectional current

Single/Dual/Quad, High-Side Current-Sense Amplifiers with Internal Gain

Table 1. Recommended Component Values

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

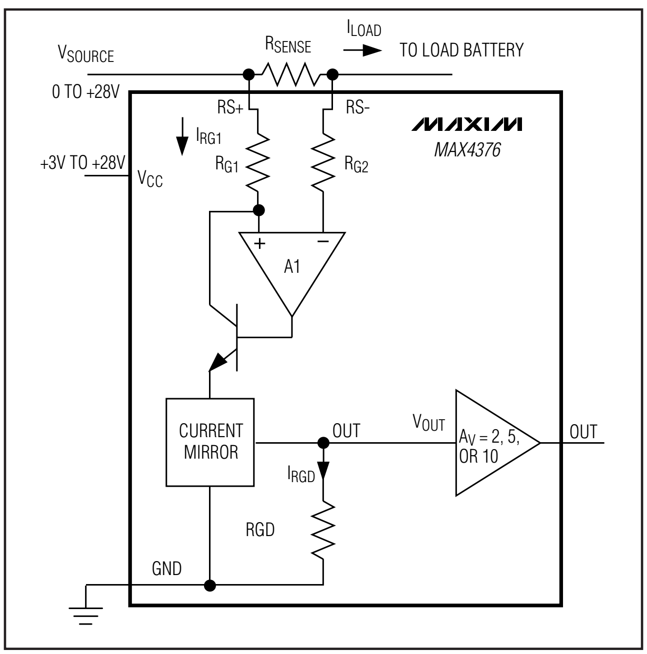


Figure 1. Functional Diagram

monitor. This is useful for implementing either smart battery packs or fuel gauges.

Current Source Circuit

Figure 3 shows a block diagram using the MAX4376 with a switching regulator to make a current source.

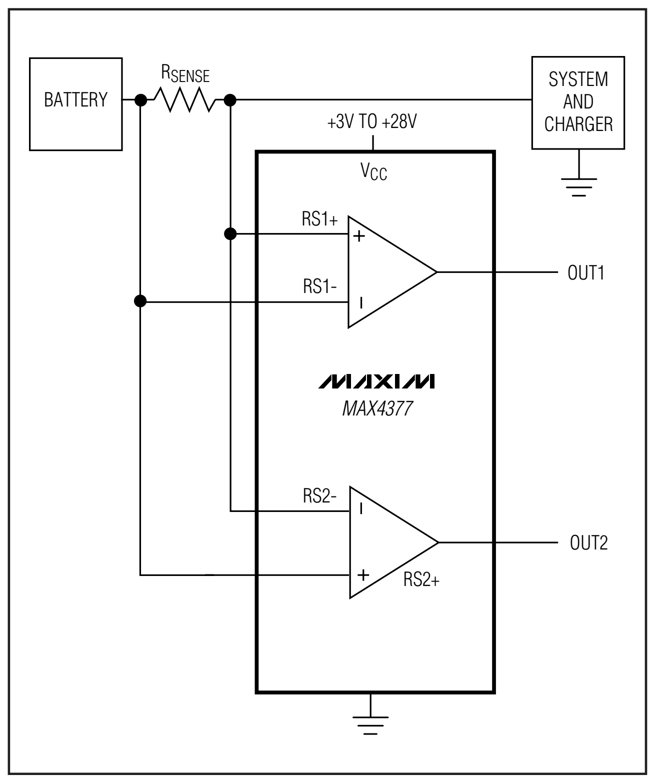


Figure 2. Bidirectional Current Monitor

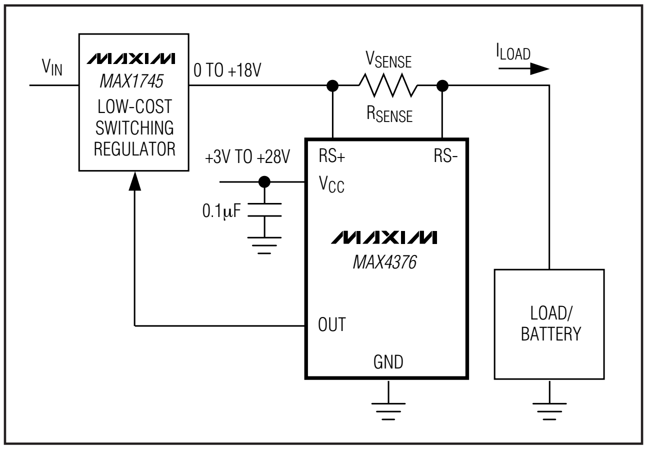
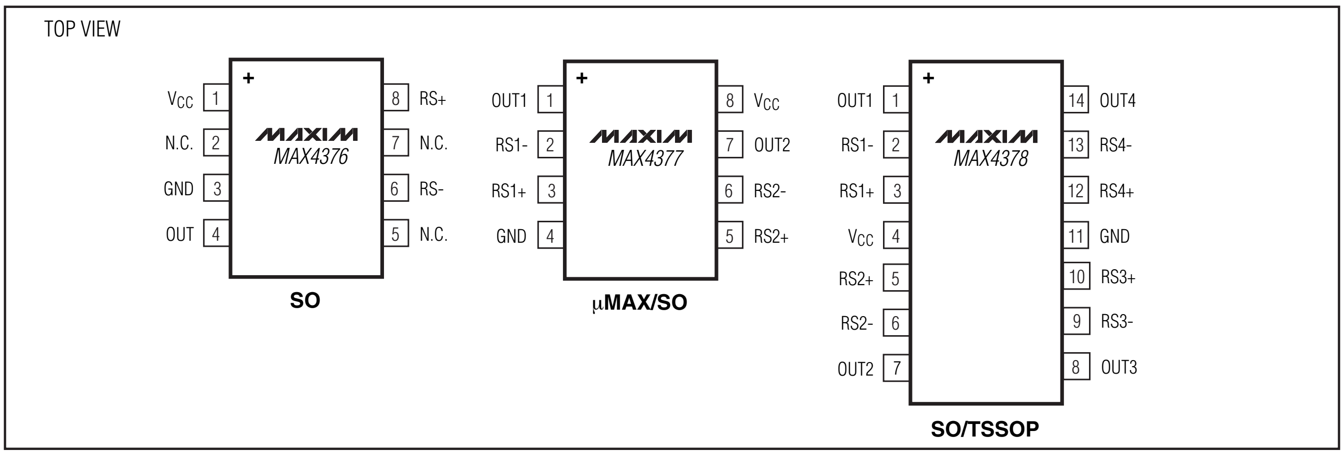


Figure 3. Current Source

Chip Information

MAX4376_ TRANSISTOR COUNT: 162
MAX4377_ TRANSISTOR COUNT: 324
MAX4378_ TRANSISTOR COUNT: 648
PROCESS: BiCMOS

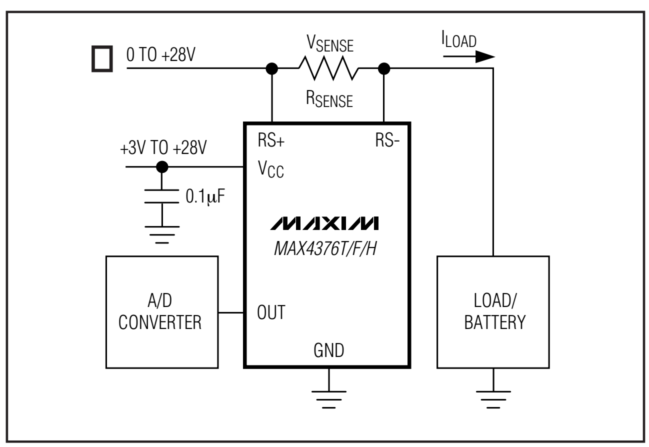
Pin Configurations (continued)



Ordering Information (continued)

PART	GAIN (+V/V)	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX4377TAUA+	20	-40°C to +125°C	8 µMAX	—
MAX4377FAUA+	50	-40°C to +125°C	8 µMAX	—
MAX4377HAUA+	100	-40°C to +125°C	8 µMAX	—
MAX4377TASA+	20	-40°C to +125°C	8 SO	—
MAX4377FASA+	50	-40°C to +125°C	8 SO	—
MAX4377HASA+	100	-40°C to +125°C	8 SO	—
MAX4378TAUD+	20	-40°C to +125°C	14 TSSOP	—
MAX4378FAUD+	50	-40°C to +125°C	14 TSSOP	—
MAX4378HAUD+	100	-40°C to +125°C	14 TSSOP	—
MAX4378TASD+	20	-40°C to +125°C	14 SO	—
MAX4378FASD+	50	-40°C to +125°C	14 SO	—
MAX4378HASD+	100	-40°C to +125°C	14 SO	—

Typical Operating Circuit



Single/Dual/Quad, High-Side Current-Sense Amplifiers with Internal Gain

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
4	4/09	Added automotive part number and lead-free designations	1, 9