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36V, Input Common-Mode, High-Precision, Low-Power Current-Sense Amplifier

MAX44284

General Description

The MAX44284 is a high-side, current-sense amplifier that operates with a 1.7V to 5.5V single supply and is optimized for very low power operation with only 21µA of quiescent current.

The MAX44284 offers precision accuracy specifications of 2µV V_{OS} and gain error of 0.05%. The device features an input common-mode voltage range from -0.1V to +36V. This current-sense amplifier has a voltage output and is offered in four different gain versions.

The MAX44284 is offered in small 6-bump, 0.4mm-pitch WLP (1.3mm x 0.9mm) and 6-pin SOT23 packages and is specified for operation over the -40°C to +125°C automotive temperature range.

Applications

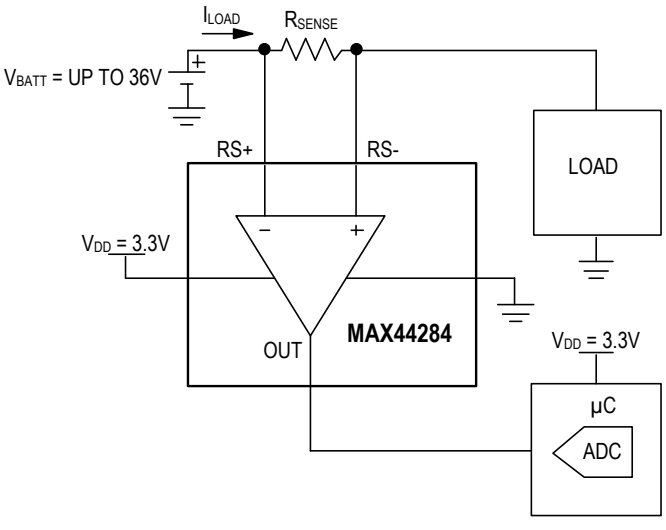
- Smartphones and Tablets
- Notebook Computers
- DC-DC Current Sensing in Power Management
- Portable-/Battery-Powered Systems
- Medical Pulse Oximeters and Infusion Pumps
- Base Stations

***Ordering Information* appears at end of data sheet.**

Benefits and Features

- Supports Use of Small Current-Sense Resistors to Improve Power-Supply Conversion Efficiency and Measurement Accuracy
  - Input Bias Current of 80nA (max)
  - Very Low 2µV Input Offset Voltage (MAX44284F/H)
  - Extremely Low 50nV/°C Input Offset Tempco Coefficient
  - -0.1V to +36V Wide Input Common-Mode Range
  - Low 0.05% Gain Error
- Extends Battery Life
  - Low Supply Current of 21µA
  - 1.7V to 5.5V Single Supply
  - Shutdown Input (Independent of V_{DD})
- Four Fixed Gain Options Simplify Design
  - 50V/V – MAX44284F
  - 100V/V – MAX44284H
  - 200V/V – MAX44284W
  - 500V/V – MAX44284E

Typical Application Circuit



19-6862; Rev 10; 6/20

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Absolute Maximum Ratings

V_{DD} to GND .....-0.3V to +6V
RS+, RS- to GND .....-0.3V to +40V
RS+ to RS- .....±40V
OUT, $\overline{SHDN}$ to GND .....-0.3V to (V_{DD} + 0.3V)
Continuous Input Current (any pin) .....±20mA
Continuous Power Dissipation (T_A = +70°C)
WLP (derate 10.5mW/°C above +70°C) 840mW
SOT23 (derate 4.3mW/°C above +70°C) 347.8mW

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
Soldering Temperature (reflow) .....+260°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.

Package Information

6 SOT23

PACKAGE CODE	U6+1, U6+1A
Outline Number	21-0058
Land Pattern Number	90-0175
Thermal Resistance, Single-Layer Board:	
Junction to Ambient - θ_{JA} (C/W)	N/A
Junction to Case - θ_{JC} (C/W)	80
Thermal Resistance, Multi-Layer Board	
Junction to Ambient (θ_{JA}) (C/W)	115
Junction to Case (θ_{JC}) (C/W)	80

6 WLP

PACKAGE CODE	W60A1+1
Outline Number	21-0656
Land Pattern Number	Refer to Application Note 1891
Thermal Resistance, Multi-Layer Board	
Junction to Ambient (θ_{JA}) (C/W)	95.15
Junction to Case (θ_{JC}) (C/W)	N/A

For the latest package outline information and land patterns (footprints), go to www.maximintegrated.com/packages. 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 thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to www.maximintegrated.com/thermal-tutorial.

Electrical Characteristics

(V_{DD} = 3.3V, V_{CM} = 12V, V_{SENSE} = V_{FS}/2, V_{FS} = (V_{DD} - V_{OH} - V_{OL})/Gain, $V_{\overline{SHDN}}$ = V_{DD}, R_L = 10kΩ to GND, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
POWER SUPPLY						
Supply Voltage	V_{DD}	Guaranteed by PSRR	1.7		5.5	V
Shutdown Supply Current	$I_{\overline{SHDN}}$			0.3	0.8	µA
Supply Current	I_{DD}	T_A = +25°C, R_L= ∞		21	31.2	µA
		-40°C ≤ T_A ≤ +125°C, R_L= ∞			41.5	
Power-Supply Rejection Ratio	PSRR	1.7V ≤ V_{DD} ≤ 5.5V, V_{OUT} = 1V	100	110		dB
Shutdown Voltage Low	V_{IL}				0.55	V
Shutdown Voltage High	V_{IH}		1.3			V
DC CHARACTERISTICS						
Input Common-Mode Voltage Range	V_{CM}	Guaranteed by CMRR	-0.1		+36	V
Common-Mode Rejection Ratio (Note 5)	CMRR	-0.1V ≤ V_{CM} ≤ +36V, V_{CM} = RS-	91.3	140		dB
		+0.1V ≤ V_{CM} ≤ +36V, V_{CM} = RS- (Note 7)	120	145		
Input Bias Current	I_{RS+}, I_{RS-}			2	80	nA
Input Offset Current	I_{OS}			2	50	nA
Input Offset Voltage (Note 3)	V_{OS}	MAX44284F (T_A = +25°C)		±2	±10	µV
		MAX44284F (-40°C ≤ T_A ≤ +125°C)			±28	
		MAX44284H (T_A = +25°C)		±2	±12	
		MAX44284H (-40°C ≤ T_A ≤ +125°C)			±28	
		MAX44284W (T_A = +25°C)		±10	±20.5	
		MAX44284W (-40°C ≤ T_A ≤ +125°C)			±38	
		MAX44284E (T_A = +25°C)		±15	±26	
		MAX44284E (-40°C ≤ T_A ≤ +125°C)			±40	
Input Offset Voltage Temperature Drift	TCV_{OS}			50		nV/°C
Gain	G	MAX44284F		50		V/V
		MAX44284H		100		
		MAX44284W		200		
		MAX44284E		500		

Electrical Characteristics (continued)

(V_{DD} = 3.3V, V_{CM} = 12V, V_{SENSE} = V_{FS}/2, V_{FS} = (V_{DD} - V_{OH} - V_{OL})/Gain, $V_{\overline{SHDN}}$ = V_{DD}, R_L = 10kΩ to GND, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Gain Error (Note 4)	GE	MAX44284F (T_A = +25°C)		0.05	0.15	%
		MAX44284F (-40°C ≤T_A≤ +125°C)			0.20	
		MAX44284H (T_A = +25°C)		0.05	0.15	
		MAX44284H (-40°C ≤ T_A ≤ +125°C)			0.26	
		MAX44284W (T_A = +25°C)		0.05	0.15	
		MAX44284W (-40°C ≤ T_A ≤ +125°C)			0.35	
		MAX44284E (T_A = +25°C)		0.05	0.16	
		MAX44284E (-40°C ≤ T_A ≤ +125°C)			0.39	
Output Voltage High	V_{OH}	V_{OH} = V_{DD} - V_{OUT}, R_L = 10kΩ to GND		25	35	mV
		I_{SOURCE} = 100µA			20	
Output Voltage Low	V_{OL}	No load		0.3	1	mV
		I_{SINK} = 100µA			20	
Input Differential Impedance				6		MΩ
Output Impedance				200		mΩ
AC CHARACTERISTICS						
Small-Signal Bandwidth	BW_{3dB}	MAX44284F		3		kHz
		MAX44284H		1.8		
		MAX44284W		1		
		MAX44284E		0.4		
Input Voltage-Noise Density	e_n	f = 1kHz		150		nV/√Hz
AC Common-Mode Rejection Ratio	AC CMRR	f = 10kHz, 600mV_{P-P} sinusoidal waveform		80		dB

Electrical Characteristics (continued)

(V_{DD} = 3.3V, V_{CM} = 12V, V_{SENSE} = V_{FS}/2, V_{FS} = (V_{DD} - V_{OH} - V_{OL})/Gain, $V_{\overline{SHDN}}$ = V_{DD}, R_L = 10kΩ to GND, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

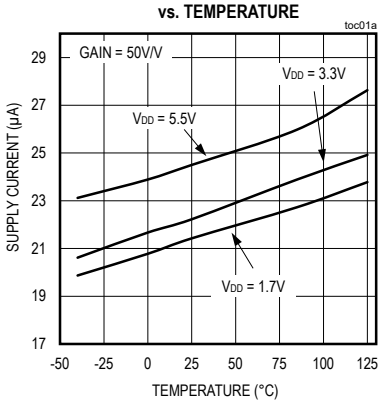
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Settling Time	t_S	V_{OUT} from 250mV to 2.5V, Gain = 50, within 12-bit accuracy		1500		µs
		V_{OUT} from 250mV to 2.5V, Gain = 100, within 12-bit accuracy		1500		
		V_{OUT} from 250mV to 2.5V, Gain = 200, within 12-bit accuracy		1800		
		V_{OUT} from 250mV to 2.5V, Gain = 500, within 12-bit accuracy		4000		
Capacitive Load	C_L	R_{ISO} = 0Ω		500		pF
		R_{ISO} = 20Ω		2200		

Note 2: All devices are 100% production tested at T_A = +25°C. All temperature limits are guaranteed by design.
Note 3: V_{OS} is calculated by applying two values of V_{SENSE} (10% of full-scale range to 90% of full-scale range).
Note 4: Gain error is calculated by applying two values of V_{SENSE} (10% of full-scale range to 90% of full-scale range) and calculating the error of the slope vs. the ideal.
Note 5: CMRR measurement is done at V_{OUT} = V_{DD}/2 condition.
Note 6: PSRR measurement is done at V_{OUT} = 1V condition.
Note 7: Parameter is guaranteed by design.

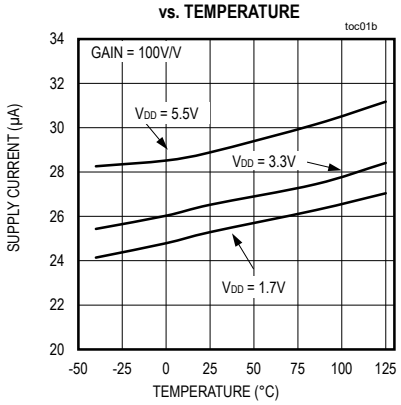
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

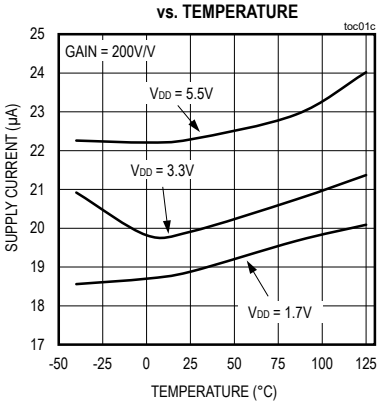
SUPPLY CURRENT vs. TEMPERATURE



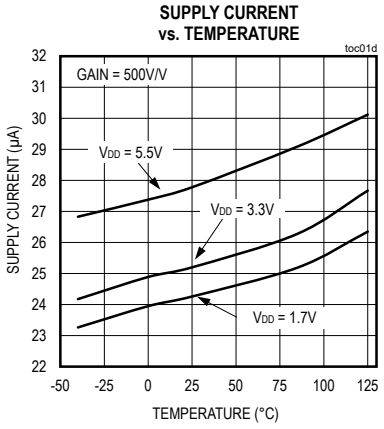
SUPPLY CURRENT vs. TEMPERATURE



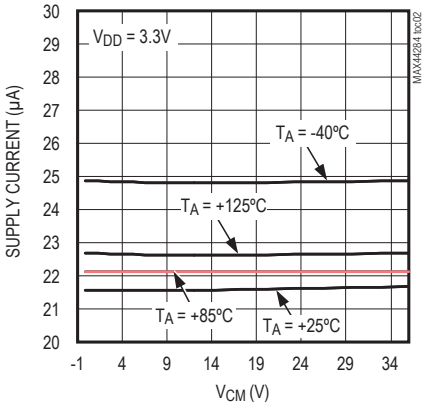
SUPPLY CURRENT vs. TEMPERATURE



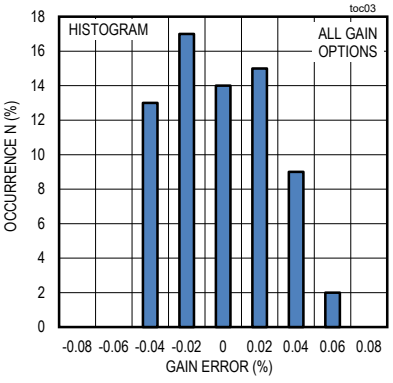
SUPPLY CURRENT vs. TEMPERATURE



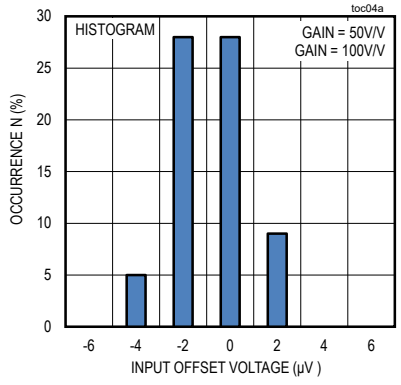
SUPPLY CURRENT vs. COMMON VOLTAGE



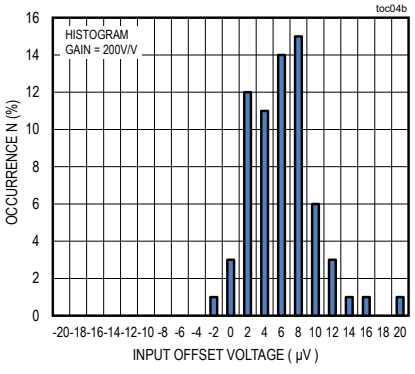
GAIN ERROR HISTOGRAM



INPUT OFFSET VOLTAGE HISTOGRAM



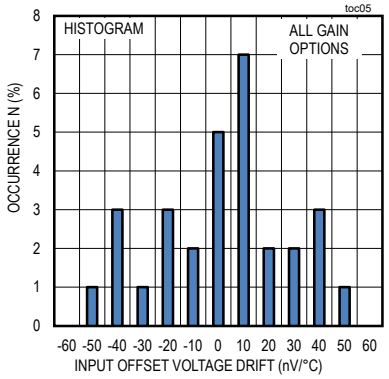
INPUT OFFSET VOLTAGE HISTOGRAM



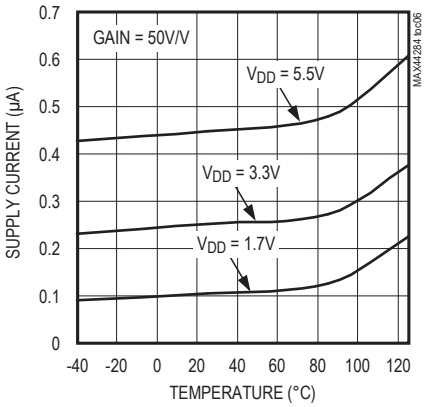
Typical Operating Characteristics (continued)

(T_A = +25°C, unless otherwise noted.)

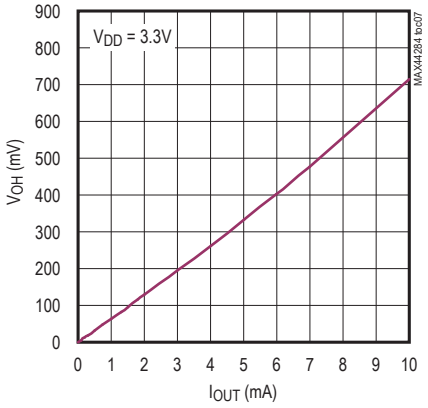
INPUT OFFSET VOLTAGE DRIFT HISTOGRAM



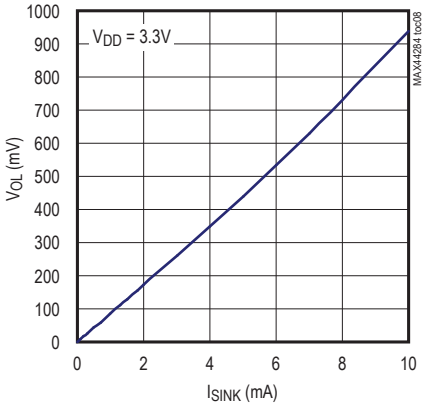
SHUTDOWN SUPPLY CURRENT vs. TEMPERATURE



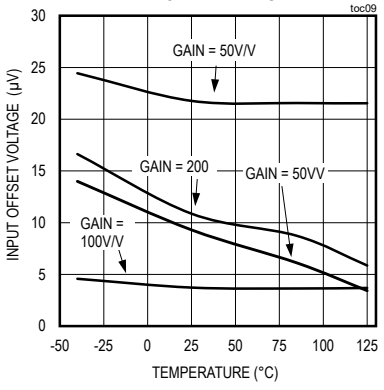
V_{OH} vs. I_{OUT}



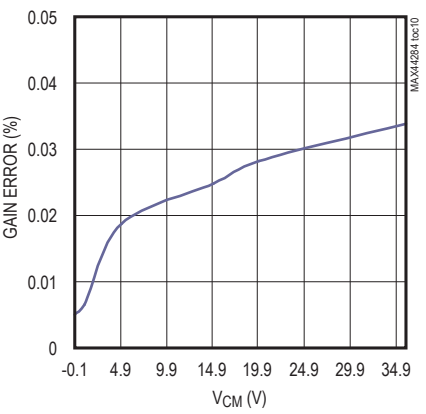
V_{OL} vs. I_{SINK}



INPUT OFFSET VOLTAGE vs. TEMPERATURE



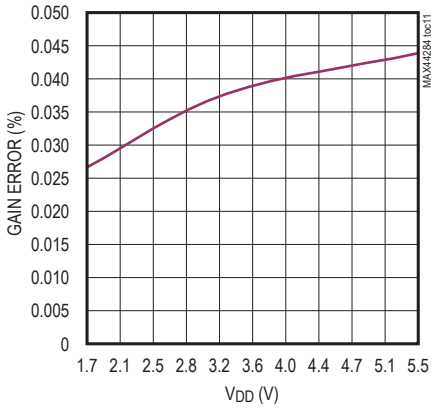
GAIN ERROR vs. INPUT COMMON-MODE VOLTAGE



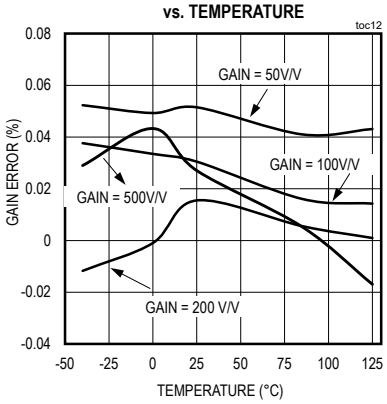
Typical Operating Characteristics (continued)

(T_A = +25°C, unless otherwise noted.)

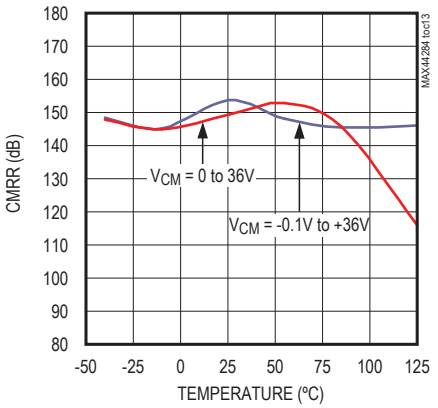
GAIN ERROR vs. SUPPLY VOLTAGE



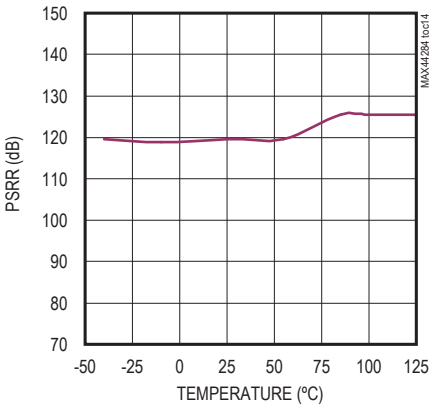
GAIN ERROR vs. TEMPERATURE



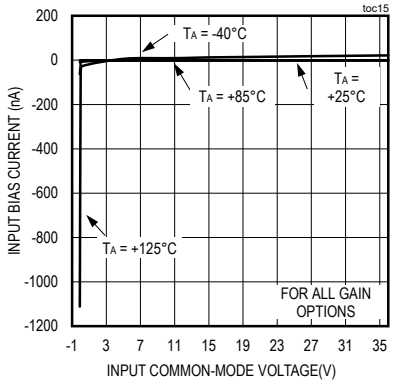
COMMON-MODE REJECTION RATIO vs. TEMPERATURE



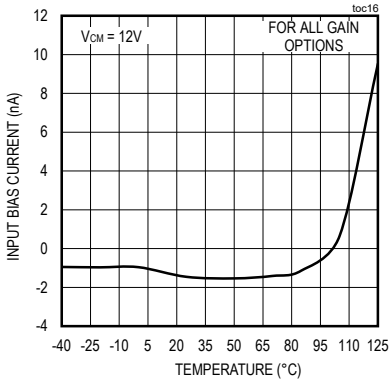
POWER-SUPPLY REJECTION RATIO vs. TEMPERATURE



INPUT BIAS CURRENT vs. INPUT COMMON-MODE VOLTAGE



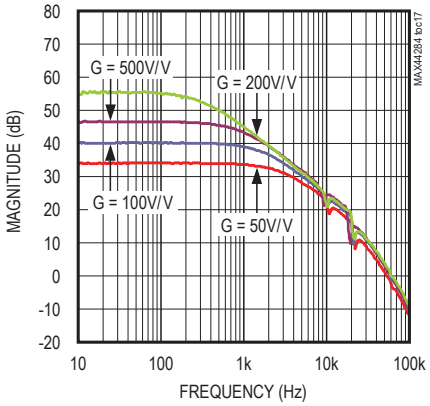
INPUT BIAS CURRENT vs. TEMPERATURE



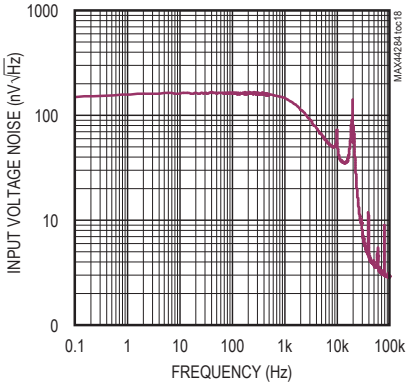
Typical Operating Characteristics (continued)

(T_A = +25°C, unless otherwise noted.)

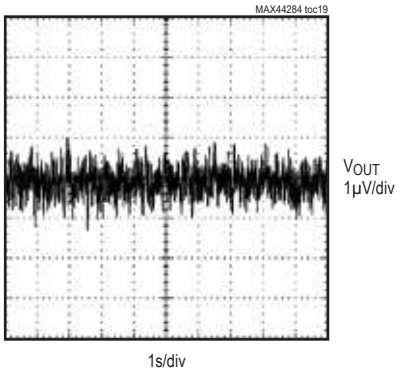
GAIN vs. FREQUENCY



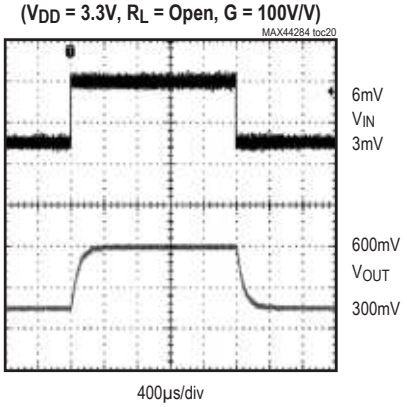
INPUT-VOLTAGE NOISE vs. FREQUENCY



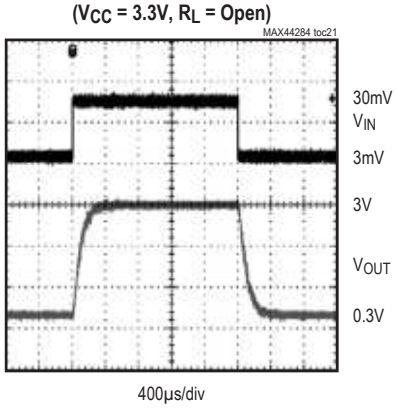
0.1Hz TO 10Hz PEAK-TO-PEAK NOISE



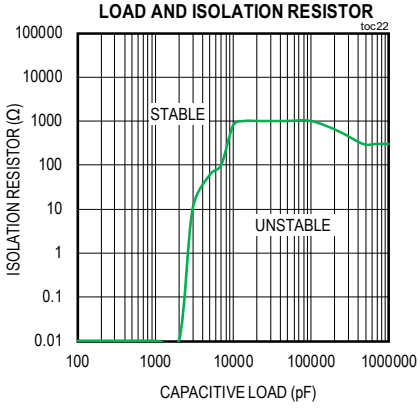
SMALL-SIGNAL INPUT STEP RESPONSE
(V_{DD} = 3.3V, R_L = Open, G = 100V/V)



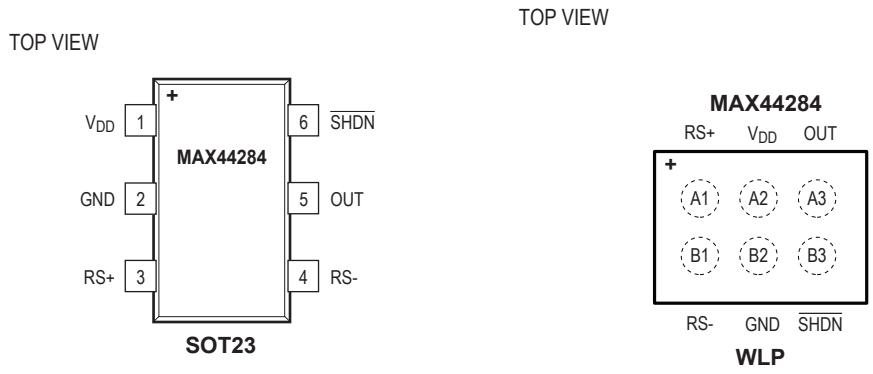
LARGE-SIGNAL INPUT STEP RESPONSE
(V_{CC} = 3.3V, R_L = Open)



STABILITY vs. CAPACITIVE LOAD AND ISOLATION RESISTOR



Pin Configurations



Pin Description

PIN	BUMP	NAME	FUNCTION
SOT23	WLP		
1	A2	V_{DD}	Power-Supply Voltage Input. Bypass V_{DD} to GND with 0.1µF and 4.7µF capacitors in parallel as close as possible to the device.
2	B2	GND	Ground
3	A1	RS+	External Sense Resistor Power-Side Connection
4	B1	RS-	External Sense Resistor Load-Side Connection
5	A3	OUT	Output Voltage. V_{OUT} is proportional to $V_{SENSE} = V_{RS+} - V_{RS-}$.
6	B3	$\overline{SHDN}$	Active-Low Shutdown Input. Connect to V_{DD} for normal operation.

Detailed Description

The MAX44284 family features a single-supply; high-accuracy unidirectional, current-sense amplifier in various gain options and a -0.1V to 36V input common-mode range that is independent of supply voltage (V_{DD}). The MAX44284 is ideal for many battery-powered, handheld devices because it uses only maximum 31.2µA quiescent supply current to extend battery life. The device's low input offset voltage, tight gain error, and low temperature drift characteristics allow the use of small-sense resistors for current measurements to improve power-supply conversion efficiency and accuracy of measurements. This feature allows monitoring of power-supply load current even if the rail is shorted to ground. High-side current monitoring does not interfere with the ground path of the load being measured, making the IC particularly useful in a wide range of high-reliability systems.

Because of its extended common-mode range below ground, this part can also be used as a low-side current sensing element.

Shutdown

The MAX44284 features active-low logic shutdown input to reduce the supply current. Drive $\overline{SHDN}$ high for normal operation. Drive $\overline{SHDN}$ low to place the device in shutdown mode. In shutdown mode, the supply current drawn from the V_{DD} is less than 1µA (max).

Precision

The MAX44284 uses capacitive-coupled Instrumentation amplifier architecture that enables the part to achieve over the top common-mode voltage ranges, high power efficiency, high gain accuracy, and low-power design.

Low Offset Voltage and Low Gain Error

The MAX44284 utilizes Capacitive-Coupled Chopper Instrumentation Amplifier (CCIA) architecture to achieve a low-input offset voltage of less than 10µA. These techniques also enable extremely low-input offset voltage drift over time and temperature to 50nV/°C. The precision V_{OS} specification allows accurate current measurements with lower values of current-sense resistors, thus reducing power dissipation in battery-powered systems, as well as load regulation issues in low-voltage DC power supplies.

Working with error tolerances with very few internal blocks in this architecture is instrumental in achieving a gain error of less than 0.20% over the entire temperature range of -40°C to +125°C.

Applications Information

Input Differential Signal Range

The MAX44284's input structure is optimized for sensing small differential signals as low as 3.4mV full scale (V_{FS}) for high efficiency with lowest power dissipation in the sense resistor, or 110mV full scale for high dynamic range. The input differential signal range is determined by the following equation for the MAX44248 family.

$$V_{(SENSE\ RANGE)} = \frac{V_{DD}}{GAIN}$$

The input differential voltage range is estimated for V_{DD} from 1.7V to 5.5V for different gain values of the MAX44284 as shown in Table 1.

Ideally, the maximum load current develops the full-scale sense voltage across the current-sense resistor. Choose the gain needed to yield the maximum output voltage required for the application:

$$V_{OUT} = GAIN \times V_{SENSE}$$

Choosing the Sense Resistor

Voltage Loss

A high R_{SENSE} value causes the power-source voltage to drop due to IR loss. For minimal voltage loss, use the lowest R_{SENSE} value.

Accuracy

Use the below linear equation to calculate total error:

$$V_{OUT} = (GAIN \pm GE) \times V_{SENSE} \pm (GAIN \times V_{OS})$$

Table 1. V_{SENSE} Input Range

PART	GAIN (V/V)	V_{SENSE} RANGE (mV) with V_{DD} (1.7V)	V_{SENSE} RANGE (mV) with V_{DD} (5.5V)
MAX44284F	50	34	110
MAX44284H	100	17	55
MAX44284W	200	8.5	27.5
MAX44284E	500	3.4	11

A high R_{SENSE} value allows lower currents to be measured more accurately because offsets are less significant when the sense voltage is larger. Note that the tolerance and temperature coefficient of the chosen resistors directly affect the precision of any measurement system. For best performance, select R_{SENSE} to provide approximately maximum input differential sense voltage of 110mV (MAX44284F) or 55mV (MAX44284H) or 27.5mV (MAX44284W) or 11mV (MAX44284E) of sense voltage for the full-scale current in each application. Sense resistors of 5mΩ to 100mΩ are available with 1% accuracy or better.

Efficiency and Power Dissipation

At high current levels, the I^2R losses in R_{SENSE} can be significant. This should be taken into consideration when choosing the resistor value and its power dissipation (wattage) rating. The sense resistor's value will drift if it is allowed to heat up excessively. The precision V_{OS} of the MAX44284 allows the use of small sense resistors to reduce power dissipation and reduce hot spots.

Kelvin Connections

Because of the high currents that may flow through R_{SENSE} based on the application, take care to eliminate solder and parasitic trace resistance from causing errors in the sense voltage. Either use a four-terminal current-sense resistor or use Kelvin (force and sense) PCB layout techniques.

Input Filtering

Some applications of current-sense amplifiers need to measure currents accurately even in the presence of both differential and common-mode ripple, as well as a wide variety of input transient conditions.

The MAX44284 allows two methods of filtering to help improve performance in the presence of input common-mode voltage and input differential voltage transients. Figure 1 shows a differential input filter. The capacitor C_{IN} across RS+ and RS- along with the resistor R_{IN} helps filter against input differential voltages and prevents them from reaching the MAX44284. The corner frequency of this filter is determined by the choice of R_{IN}, C_{IN}. Figure 2 shows a common-mode input filter. The choice of capacitance depends on corner frequency after R_{IN} is chosen. In case of mismatch or error in application design, an additional DC error is accumulated as offset voltage and increased gain error.

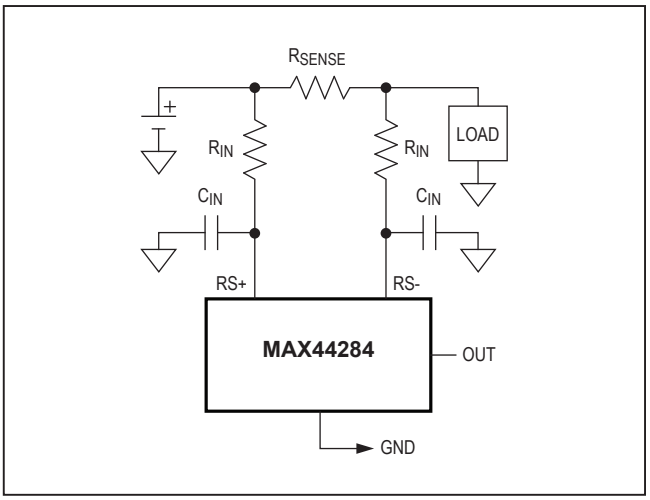


Figure 1. Differential Input Filtering

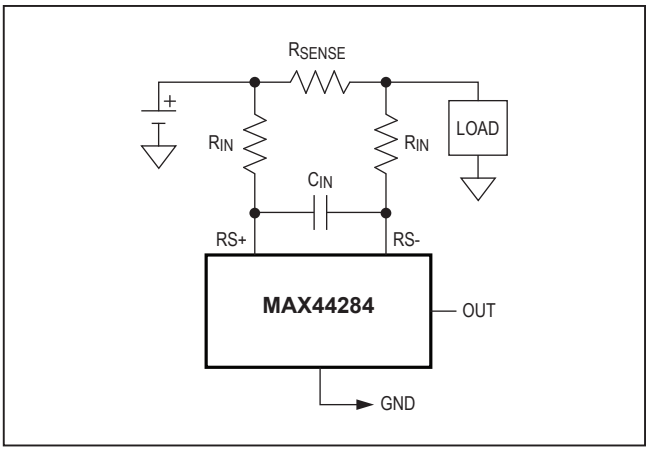


Figure 2. Input Common-Mode Filtering

$$V_{OS} = (R_{IN} \times I_{OFFSET}) + (DR_{IN} \times I_{BIAS})$$

DR_{IN} is the resistance mismatch in R_{IN} at RS+ and RS-. If DR_{IN} is too small, its effect can be neglected. Since I_{OFFSET} of the MAX44284 is smaller than 2nA, and if we want to make sure V_{OS} is lesser than 1µV range, choosing

$$R_{IN} < (V_{OS} \div I_{OFFSET})$$

For gain error, it depends on its input impedance and R_{IN}.

$$GainError = 2 \times \frac{R_{IN}}{Z_{IN}}$$

Avoid additional gain error shift due to the effect of R_{IN}. For gain error, the MAX44284 is 0.15%. If the margin of additional effect of R_{IN} results in a gain error shift of less than 0.02%, then:

$$R_{IN} < Z_{IN} \times (\frac{0.02\%}{2}) = 600\Omega$$

So R_{IN} can be chosen ≤ 500Ω.

Output Filtering

The internal architecture of the MAX44284 suppresses the DC offset, 1/f noise, and accumulates at higher frequencies so that they can be filtered out. Hence, minute AC disturbances can be observed at 10kHz and 20kHz. It is recommended to add an output filter after the MAX44284 to avoid noise and unwanted frequency disturbances at the output with 4kHz -3dB f_C (see Figure 3).

(Suggested values of C and R: 22nF and 1.8kΩ, respectively.)

Note that load capacitance greater than approximately 2nF may cause instability unless a series resistor is present to help isolate the capacitor from the amplifier output. Output stability with different values of load capacitor and isolation resistor is shown in TOC22 of the *Typical Operating Characteristics*.

Bidirectional Application

Battery-powered systems may require a precise bidirectional current-sense amplifier to accurately monitor the battery's charge and discharge currents. Measurements of the two separate outputs with respect to GND yield an accurate measure of the charge and discharge currents, respectively (Figure 4).

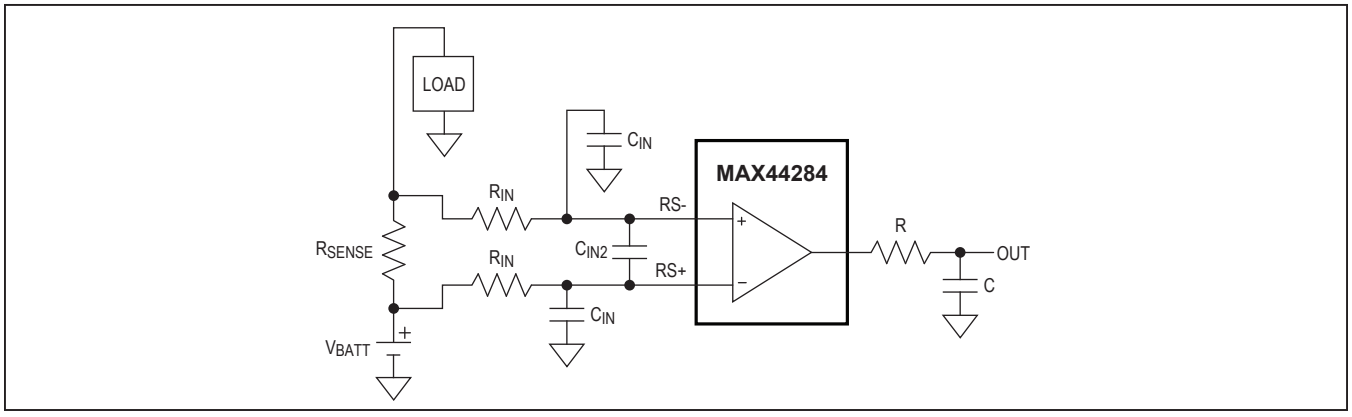


Figure 3. Filtering

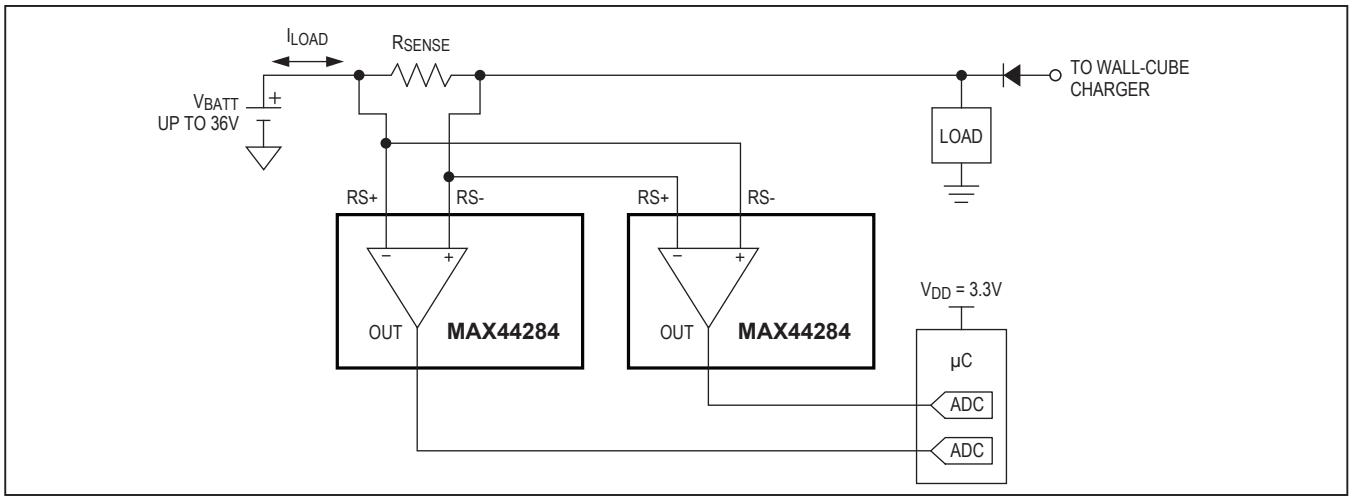


Figure 4. Bidirectional Application

Ordering Information

PART	GAIN (V/V)	TEMP RANGE	PIN-PACKAGE	TOP MARK
MAX44284FAWT+	50	-40°C to +125°C	6 WLP	+CX
MAX44284FAUT+	50	-40°C to +125°C	6 SOT23	+ACSF
MAX44284FAUT/V+T*	50	-40°C to +125°C	6 SOT23	—
MAX44284HAWT+	100	-40°C to +125°C	6 WLP	+CY
MAX44284HAUT+	100	-40°C to +125°C	6 SOT23	+ACSG
MAX44284WAWT+	200	-40°C to +125°C	6 WLP	+CZ
MAX44284WAUT+	200	-40°C to +125°C	6 SOT23	+ACSH
MAX44284EAWT+	500	-40°C to +125°C	6 WLP	+DA
MAX44284EAUT+	500	-40°C to +125°C	6 SOT23	+ACSI

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

**Future product—contact factory for availability.*

Chip Information

PROCESS: BiCMOS

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	12/13	Initial release	—
1	5/14	Updated *Typical Operating Characteristics* and the *Ordering Information*	8, 13
2	6/14	Corrected *General Description* and updated *Electrical Characteristics* globals	1–4
3	9/14	Released MAX44284E and updated the *Electrical Characteristics*	3, 13
4	1/15	Revised *Benefits and Features* section	1
5	11/17	Corrected typo in *Output Filtering* section	12
6	6/18	Updated TOC22	8
7	7/18	Updated *Ordering Information* table	13
8	8/18	Updated *Package Information* section and *Typical Operating Characteristics*	2, 8
9	5/19	Updated *Typical Operating Characteristics* and *Output Filtering* section	9, 13
10	6/20	Updated *Electrical Characteristics* table and *Input Filtering* section	3, 13

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