19-4251; Rev 0; 8/08

-0.1V to +28V Input Range, Micropower, Uni-/Bidirectional, Current-Sense Amplifiers

General Description

The MAX9928/MAX9929 low-cost, uni-/bidirectional, high-side, current-sense amplifiers are ideal for monitoring battery charge and discharge currents in notebooks, cell phones, and other portable equipment. These devices feature a wide -0.1V to +28V input common-mode voltage range, low 20µA supply current with V_{OS} less than 0.4mV, and a gain accuracy better than 1.0%. The input common-mode range is independent of the supply voltage, ensuring that the current-sense information remains accurate even when the measurement rail is shorted to ground.

The MAX9928F/MAX9928T feature a current output with transconductance ratios of 5µA/mV and 2µA/mV, respectively. An external resistor converts the output current to a voltage, allowing adjustable gain so that the input sense voltage can be matched to the maximum ADC input swing. The MAX9929F/MAX9929T have a voltage output and integrate a 10kΩ output resistor for fixed voltage gains of 50V/V and 20V/V, respectively.

A digital SIGN output indicates direction of current flow, so the user can utilize the full ADC input range for measuring both charging and discharging currents.

The MAX9928/MAX9929 are fully specified over the -40°C to +125°C automotive temperature range, and available in 6-bump UCSP™ (1mm x 1.5mm) and 8-pin µMAX® packages. The UCSP package is bump-to-bump compatible with the MAX4372_EBT.

UCSP is a trademark and µMAX is a registered trademark of Maxim Integrated Products, Inc.

Pin Configurations and Typical Operating Circuit appear at end of data sheet.

Features

- ♦ **Wide -0.1V to +28V Common-Mode Range, Independent of Supply Voltage**
- ♦ **2.5V to 5.5V Operating Supply Voltage**
- ♦ **20µA Quiescent Supply Current**
- ♦ **0.4mV (max) Input Offset Voltage**
- ♦ **Gain Accuracy Better than 1% (max)**
- ♦ **SIGN Output Indicates Current Polarity**
- ♦ **Two I_{OUT} Transconductance Versions Available**
  2µA/mV (MAX9928T)
  5µA/mV (MAX9928F)
- ♦ **Two V_{OUT} Gain Versions Available**
  20V/V (MAX9929T)
  50V/V (MAX9929F)
- ♦ **Pin Compatible with the MAX4372 in UCSP**
- ♦ **Available in Ultra-Small 3x2 UCSP (1mm x 1.5mm) and 8-Pin µMAX Packages**

Applications

Monitoring Charge/Discharge Currents in Portable/Battery-Powered Systems

Notebook Computers

General-System/Board-Level Current Monitoring

Smart-Battery Packs/Chargers

Precision Current Sources

Smart Cell Phones

Super Capacitor Charge/Discharge

Ordering Information

PART	OUTPUT TYPE	GAIN	PIN-PACKAGE	TOP MARK	PKG CODE
MAX9928FAUA+	Current	G_m = 5µA/mV	8 µMAX	—	U8-1
MAX9928FABT+T†	Current	G_m = 5µA/mV	3x2 UCSP	+AAA	R61A1+1
MAX9928TAUA+	Current	G_m = 2µA/mV	8 µMAX	—	U8-1
MAX9928TABT+T†	Current	G_m = 2µA/mV	3x2 UCSP	+AAC	R61A1+1
MAX9929FAUA+	Voltage	A_V = 50V/V	8 µMAX	—	U8-1
MAX9929FABT+T†	Voltage	A_V = 50V/V	3x2 UCSP	+AAB	R61A1+1
MAX9929TAUA+*	Voltage	A_V = 20V/V	8 µMAX	—	U8-1
MAX9929TABT+*†	Voltage	A_V = 20V/V	3x2 UCSP	+AAD	R61A1+1

Note: *All devices are specified over the -40°C to +125°C operating temperature range.*

+Denotes a lead-free/RoHS-compliant package.

**Future product—contact factory for availability.*

†The MAX9928_ABT and the MAX9929_ABT use Package Code R61A1+1 with backside coating to minimize die chipping.

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.

-0.1V to +28V Input Range, Micropower, Uni-/Bidirectional, Current-Sense Amplifiers

ABSOLUTE MAXIMUM RATINGS

V_{CC}, SIGN to GND ....-0.3V to +6V
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-}) .... ±30V
OUT, SIGN Short Circuit to V_{CC} or GND ....Continuous
Current into Any Pin...±20mA
Continuous Power Dissipation (T_A = +70°C)
  6-Bump 1mm x 1.5mm UCSP
    (derate 3.9mW/°C above +70°C)...........................308.3mW
  8-Pin μMAX (derate 4.8mW/°C above +70°C) 388mW

Operating Temperature Range ....-40°C to +125°C
Storage Temperature Range ....-65°C to +150°C
Junction Temperature ....+150°C
Lead Temperature (soldering, 10s) ....+300°C
Lead Temperature (reflow) ....+260°C
Bump 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.

ELECTRICAL CHARACTERISTICS

(V_{RS+} = -0.1V to +28V, V_{CC} = 3.3V, V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, R_{OUT} = 10kΩ for MAX9928_, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
AMPLIFIER DC ELECTRICAL CHARACTERISTICS							
Input Offset Voltage (Note 2)	V_{OS}	V_{RS+} = 3.6V	T_A = +25°C		±0.1	±0.4	mV
			T_A = -40°C to +125°C			±0.8	
		V_{RS+} = -0.1V	T_A = +25°C		±0.6	±1.0	
			T_A = -40°C to +125°C			±3.0	
Common-Mode Input Range	V_{CMR}	(Note 3)		-0.1		+28	V
Common-Mode Rejection Ratio	CMRR	2V ≤ V_{RS+} ≤ 28V	T_A = +25°C	93	104		dB
			T_A = -40°C to +125°C	87			
		-0.1V ≤ V_{RS+} ≤ +2V	T_A = +25°C	60	72		
			T_A = -40°C to +125°C	54			
Full-Scale Sense Voltage (Note 2)	V_{SENSE}	MAX992_F			±50		mV
		MAX992_T			±125		
Gain (Note 2)	A_V	MAX9929F			50		V/V
		MAX9929T			20		
Gain Accuracy (Notes 2, 6)		MAX9929_, V_{RS+} = 3.6V	T_A = +25°C		±0.3	±1.0	%
			T_A = -40°C to +125°C			±2.5	
		MAX9929_, V_{RS+} = -0.1V	T_A = +25°C		±0.3	±1.0	
			T_A = -40°C to +125°C			±2.8	
Transconductance (Note 2)	G_M	MAX9928F			5		μA/mV
		MAX9928T			2		

ELECTRICAL CHARACTERISTICS (continued)

(V_{RS+} = -0.1V to +28V, V_{CC} = 3.3V, V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, R_{OUT} = 10kΩ for MAX9928_, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Transconductance Accuracy (Note 2)		MAX9928_, V_{RS+} = 3.6V	T_A = +25°C		±0.3	±1.0	%
			T_A = -40°C to +125°C			±2.5	
		MAX9928_, V_{RS+} = -0.1V	T_A = +25°C		±0.3	±1.0	
			T_A = -40°C to +125°C			±2.8	
Input Bias Current (Note 4)	I_{RS+}, I_{RS-}	2V ≤ V_{RS+} ≤ 28V		0	1.6	6	µA
		-0.1V ≤ V_{RS+} ≤ +2V		-80		+6	
Input Offset Bias Current (Note 4)	I_{OS}	2V ≤ V_{RS+} ≤ 28V			±0.05	±1	µA
		-0.1V ≤ V_{RS+} ≤ +2V			±0.2	±2	
Input Leakage Current	I_{RS+}, I_{RS-}	V_{CC} = 0V, V_{RS+} = V_{RS-} = 28V (Note 5)			0.05	1.0	µA
Output Resistance	R_{OUT}	MAX9928_			5		MΩ
		MAX9929_		6.4	10	13.6	kΩ
Output High Voltage (Note 6)	V_{OH}	MAX9928_, R_{OUT} = 10kΩ			(V_{CC} - 0.1)	(V_{CC} - 0.45)	V
		MAX9929_			(V_{CC} - 0.1)	(V_{CC} - 0.45)	
Minimum Output Voltage (Note 7)	V_{OL}	MAX9929_	T_A = +25°C		0.25	2.0	mV
			T_A = -40°C to +125°C			15	
Minimum Output Current (Note 7)	I_{OL}	MAX9928_	T_A = +25°C		0.025	0.2	µA
			T_A = -40°C to +125°C			1.5	
SIGN COMPARATOR DC ELECTRICAL CHARACTERISTICS							
Discharge to Charge Trip Point (Note 8)	V_{TDC}	V_{RS+} = 3.6V	T_A = +25°C	-1.6	-1.2	-0.5	mV
			T_A = -40°C to +125°C	-2.15		-0.15	
		V_{RS+} = -0.1V	T_A = +25°C	-2.5	-1.2	+0.25	
			T_A = -40°C to +125°C	-4.6		+2.3	
Charge to Discharge Trip Point (Note 8)	V_{TCD}	V_{RS+} = 3.6V	T_A = +25°C		-1.8		mV
		V_{RS+} = -0.1V	T_A = +25°C		-1.8		
Hysteresis Width	V_{HYS}	V_{RS+} = 3.6V, -0.1V	T_A = +25°C		0.6		mV

ELECTRICAL CHARACTERISTICS (continued)

(V_{RS+} = -0.1V to +28V, V_{CC} = 3.3V, V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, R_{OUT} = 10kΩ for MAX9928_, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Common-Mode Input Range (Note 9)	V_{CMR}		-0.1		+28	V
Common-Mode Rejection Ratio (Note 9)	CMRR	2V ≤ V_{RS+} ≤ 28V		102		dB
		-0.1V ≤ V_{RS+} ≤ +2V		74		
Output Low Voltage	V_{OL}	I_{SINK} = 100µA		0.03	0.1	V
Output High Voltage	V_{OH}			(V_{CC} - 0.01)	(V_{CC} - 0.04)	V
Internal Pullup Resistor	$R_{PULL-UP}$			1		MΩ
POWER SUPPLY						
Supply Voltage Range (Note 10)	V_{CC}	T_A = +25°C	2.5		5.5	V
		T_A = -40°C to +125°C	2.8		5.5	
Amplifier Power-Supply Rejection Ratio (Note 10)	$PSRR_A$	V_{RS+} = 3.6V	72	90		dB
		V_{RS+} = -0.1V	66	86		
Comparator Power-Supply Rejection Ratio	$PSRR_C$	V_{RS+} = 3.6V		90		dB
		V_{RS+} = -0.1V		86		
Quiescent Supply Current	I_{CC}	2V ≤ V_{RS+} ≤ 28V		20	30	µA
		-0.1V ≤ V_{RS+} < +2V		115	200	
AC ELECTRICAL CHARACTERISTICS						
-3dB Bandwidth	BW	MAX992_F, V_{SENSE} = 50mV		150		kHz
		MAX992_T, V_{SENSE} = 125mV		125		
OUT Settling to 1% of Final Value	t_{SET}	V_{RS+} = 3.6V, C_{LOAD} = 10pF, R_{OUT} = 10kΩ for MAX9928_; MAX992_F, V_{SENSE} = 5mV to 50mV step		6		µs
		MAX992_F, V_{SENSE} = 50mV to 5mV step		15		
		MAX992_T, V_{SENSE} = 5mV to 125mV step		8		
		MAX992_T, V_{SENSE} = 125mV to 5mV step		13		

ELECTRICAL CHARACTERISTICS (continued)

(V_{RS+} = -0.1V to +28V, V_{CC} = 3.3V, V_{SENSE} = (V_{RS+} - V_{RS-}) = 0V, R_{OUT} = 10kΩ, for MAX9928_, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SIGN Comparator Propagation Delay (Low to High)	t_{PROP_LH}	Overdrive = 1mV		80		µs
		Overdrive = 5mV		30		
SIGN Comparator Propagation Delay (High to Low)	t_{PROP_HL}	Overdrive = 1mV		50		µs
		Overdrive = 5mV		13		
Power-Up Time to 1% of Final Value		V_{SENSE} = 50mV for MAX992_F, V_{SENSE} = 125mV for MAX992_T, V_{RS+} = 3.6V, C_{LOAD} = 10pF		50		µs
Saturation Recovery Time		100mV ≤ V_{SENSE} ≤ 50mV for MAX992_F, 250mV ≤ V_{SENSE} ≤ 125mV for MAX992_T, V_{RS+} = 3.6V, C_{LOAD} = 10pF		4		ms

Note 1: All devices are 100% production tested at T_A = +25°C. All temperature limits are guaranteed by design.

Note 2: V_{OS} is extrapolated from two point transconductance and gain accuracy tests. Measurements are made at V_{SENSE} = +5mV and V_{SENSE} = +50mV for MAX992_F and V_{SENSE} = +5mV and V_{SENSE} = +125mV for MAX992_T. These measurements are also used to test the full-scale sense voltage, transconductance, and gain. These V_{OS} specifications are for the trimmed direction only (V_{RS+} > V_{RS-}). For current flowing in the opposite direction (V_{RS-} > V_{RS+}), V_{OS} is ±1mV (max) at +25°C and ±1.8mV (max) over temperature, when V_{RS+} is at 3.6V. See the *Detailed Description* for more information.

Note 3: Guaranteed by common-mode rejection ratio. Extrapolated V_{OS} as described in Note 2 is used to calculate common-mode rejection ratio.

Note 4: Includes input bias current of SIGN comparator.

Note 5: Leakage in to RS+ or RS- when V_{CC} = 0V. Includes input leakage current of SIGN comparator. This specification does not add to the bias current.

Note 6: Output voltage should be 650mV below V_{CC} to achieve full accuracy.

Note 7: I_{OL} is the minimum output current in the V_{SENSE} - I_{OUT} transfer characteristics. V_{OL} is the minimum output voltage in the V_{SENSE} - V_{OUT} transfer characteristic.

Note 8: V_{SENSE} voltage required to switch comparator.

Note 9: Discharge to charge trip point is functionally tested at V_{CM} = -0.1V, +3.6V, and +28V.

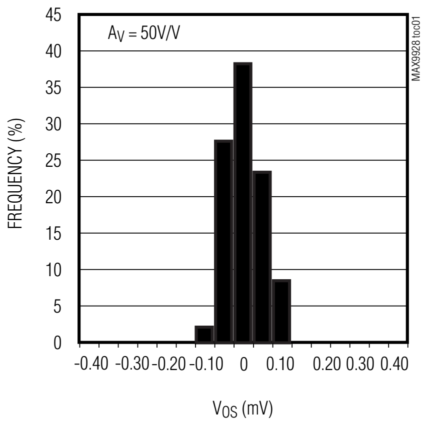
Note 10: Guaranteed by PSRR test. Extrapolated V_{OS} as described in Note 2 is used to calculate the power-supply rejection ratio. V_{SENSE} has to be such that the output voltage is 650mV below V_{CC} to achieve full accuracy.

-0.1V to +28V Input Range, Micropower, Uni-/Bidirectional, Current-Sense Amplifiers

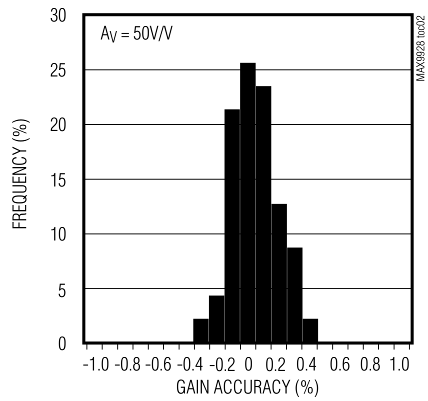
Typical Operating Characteristics

(V_{CC} = 3.3V, V_{RS+} = 12V, T_A = +25°C, unless otherwise noted.)

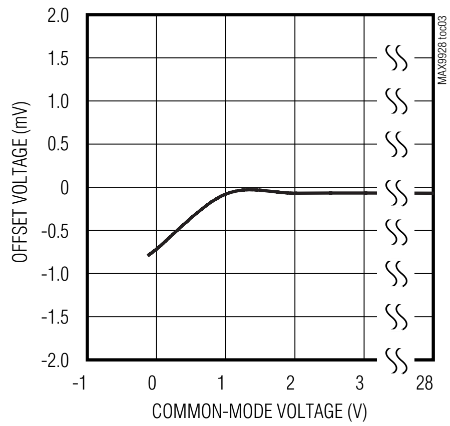
V_{OS} HISTOGRAM



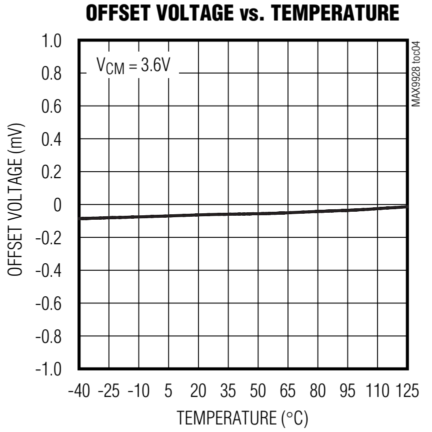
GAIN ACCURACY HISTOGRAM



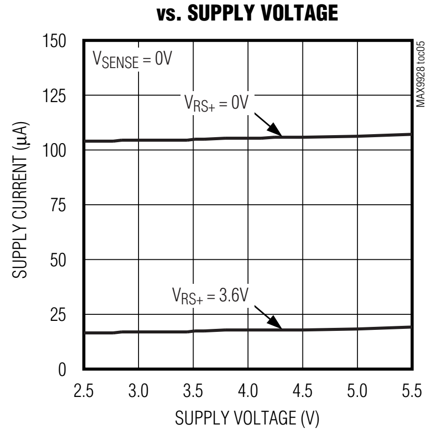
OFFSET VOLTAGE vs. COMMON-MODE VOLTAGE



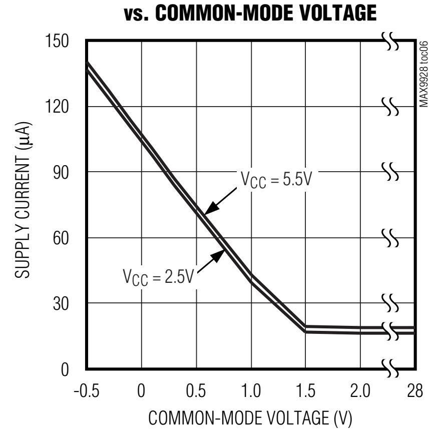
OFFSET VOLTAGE vs. TEMPERATURE



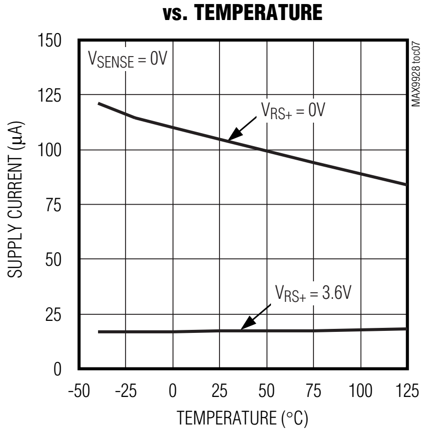
SUPPLY CURRENT vs. SUPPLY VOLTAGE



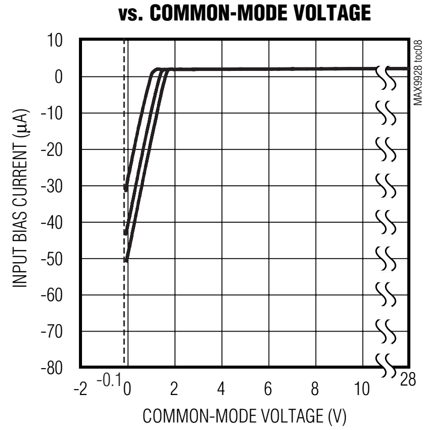
SUPPLY CURRENT vs. COMMON-MODE VOLTAGE



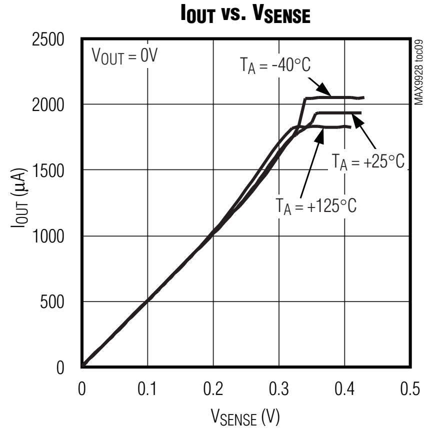
SUPPLY CURRENT vs. TEMPERATURE



INPUT BIAS CURRENT vs. COMMON-MODE VOLTAGE



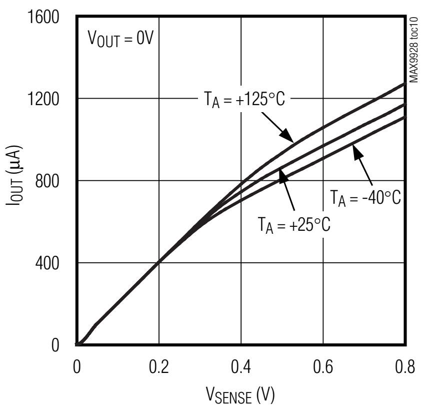
MAX9928F I_{OUT} vs. V_{SENSE}



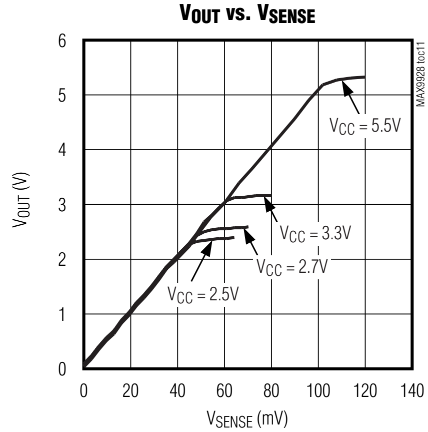
Typical Operating Characteristics (continued)

(V_{CC} = 3.3V, V_{RS+} = 12V, T_A = +25°C, unless otherwise noted.)

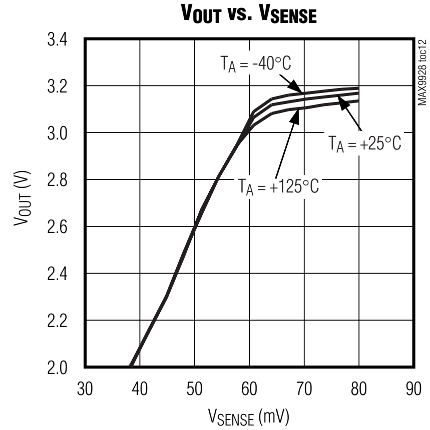
MAX9928T I_{OUT} vs. V_{SENSE}



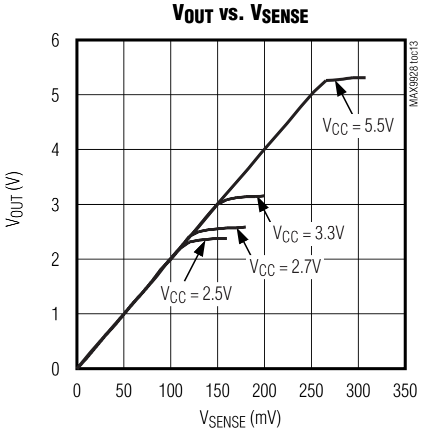
MAX9929F
V_{OUT} vs. V_{SENSE}



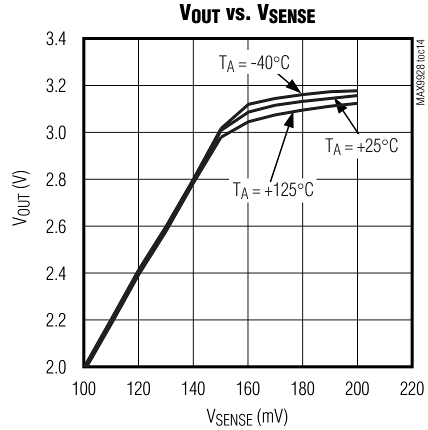
MAX9929F
V_{OUT} vs. V_{SENSE}



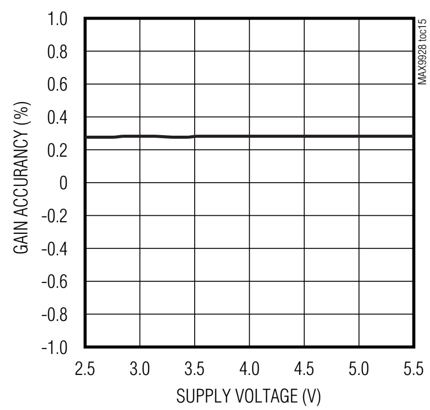
MAX9929T
V_{OUT} vs. V_{SENSE}



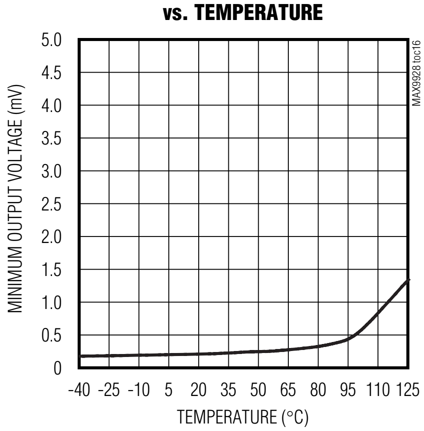
MAX9929T
V_{OUT} vs. V_{SENSE}



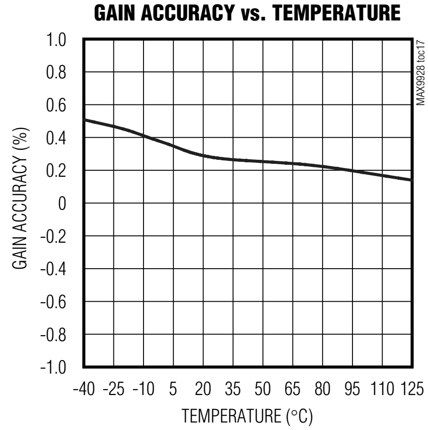
GAIN ACCURACY
vs. SUPPLY VOLTAGE



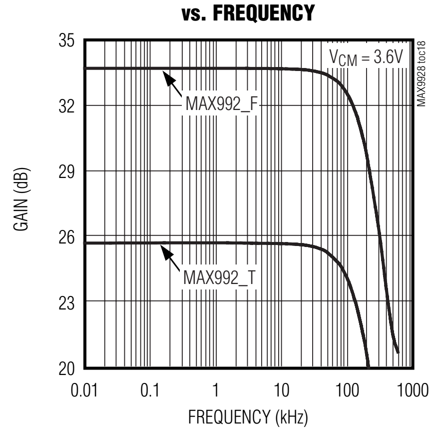
MINIMUM OUTPUT VOLTAGE
vs. TEMPERATURE



GAIN ACCURACY vs. TEMPERATURE



SMALL-SIGNAL GAIN
vs. FREQUENCY

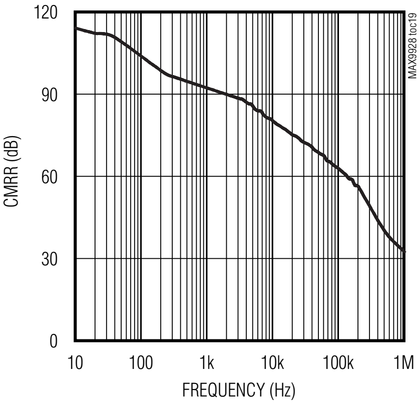


-0.1V to +28V Input Range, Micropower, Uni-/Bidirectional, Current-Sense Amplifiers

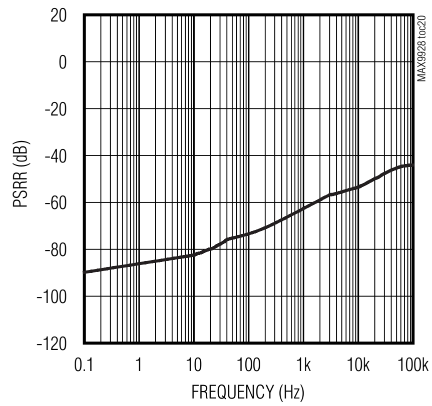
Typical Operating Characteristics (continued)

(V_{CC} = 3.3V, V_{RS+} = 12V, T_A = +25°C, unless otherwise noted.)

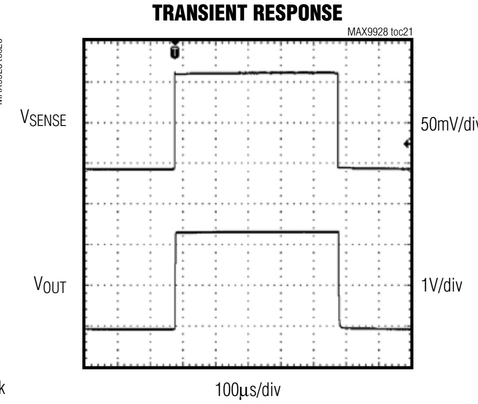
CMRR vs. FREQUENCY



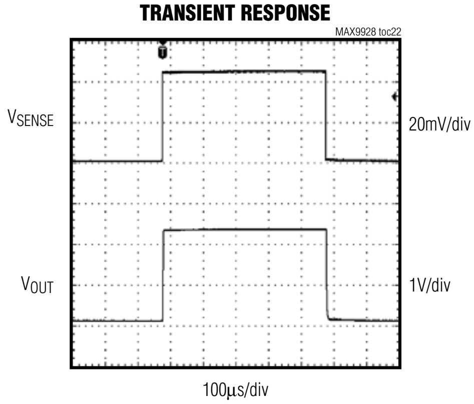
PSRR vs. FREQUENCY



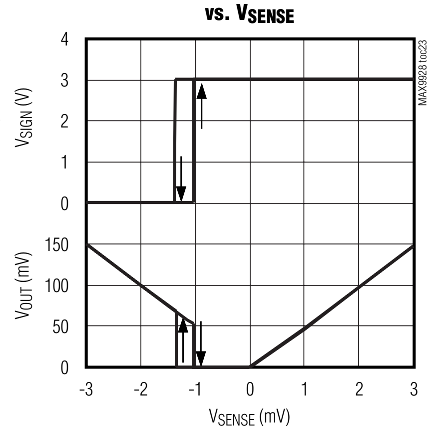
MAX9929F LARGE-SIGNAL TRANSIENT RESPONSE



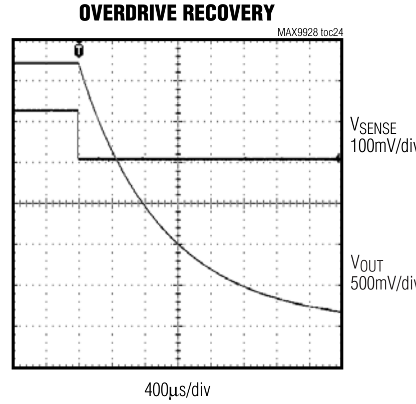
MAX9929T LARGE-SIGNAL TRANSIENT RESPONSE



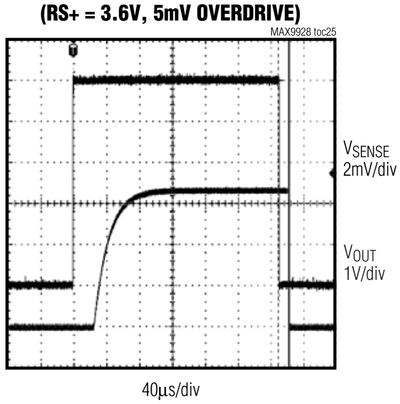
V_{SIGN} AND V_{OUT} vs. V_{SENSE}



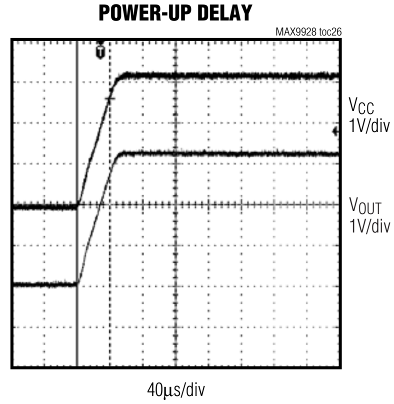
OVERDRIVE RECOVERY



COMPARATOR PROPAGATION DELAY (RS+ = 3.6V, 5mV OVERDRIVE)



POWER-UP DELAY



Pin Description

PIN µMAX	BUMP UCSP	NAME	FUNCTION
1	B3	RS-	Negative Current-Sense Input. Load-side connection for the external sense resistor.
2	B2	SIGN	SIGN Output. Indicates polarity of V_{SENSE}. SIGN = H indicates $V_{RS+} > V_{RS-}$ SIGN = L indicates $V_{RS+} < V_{RS-}$
3	B1	RS+	Positive Current-Sense Input. Power-side connection to the external sense resistor.
4, 5	—	N.C.	No Connection. Not internally connected.
6	A1	V_{CC}	Supply Voltage Input. Bypass to GND with a 0.1µF capacitor.
7	A2	GND	Circuit Ground
8	A3	OUT	Current-Sense Output. MAX9928: Current output (I_{OUT} is proportional to $\|V_{SENSE}\|$). MAX9929: Voltage output (V_{OUT} is proportional to $\|V_{SENSE}\|$).

Detailed Description

The MAX9928_/MAX9929_ micropower uni-/bidirectional, current-sense amplifiers feature -0.1V to +28V input common-mode range that is independent of the supply voltage. This wide input voltage range feature allows the monitoring of the current flow out of a power supply during short-circuit/fault conditions, and also enables high-side current sensing at voltages far in excess of the supply voltage (V_{CC}). The MAX9928_/MAX9929_ operate from a 2.5V to 5.5V single supply and draw a low 20µA quiescent supply current.

Current flows through the sense resistor, generating a sense voltage V_{SENSE} (Figure 1). The comparator senses the direction of the sense voltage and configures the amplifier for either positive or negative sense voltages by controlling the S1 and S2 switches.

For positive V_{SENSE} voltage, the amplifier's inverting input is high impedance and equals V_{IN} - V_{SENSE}. The amplifier's output drives the base of Q1, forcing its noninverting input terminal to (V_{IN} - V_{SENSE}); this causes a current to flow through R_{G1} equal to $|V_{SENSE}|/R_{G1}$. Transistor Q2 and the current mirror amplify the current by a factor of M.

For negative V_{SENSE} voltage, the amplifier's noninverting input is high impedance and the voltage on RS- terminal equals V_{IN} + V_{SENSE}. The amplifier's output drives the base of Q1 forcing its inverting input terminal to match the voltage at the noninverting input terminal; this causes a current to flow through R_{G2} equal to $|V_{SENSE}|/R_{G2}$. Again, transistor Q2 and the current mirror amplify the current by a factor of M.

+V_{SENSE} vs. -V_{SENSE}

The amplifier is configured for either positive V_{SENSE} or negative V_{SENSE} by the SIGN comparator. The comparator has a built-in offset skew of -1.2mV so that random offsets in the comparator do not affect the precision of I_{OUT} (V_{OUT}) with positive V_{SENSE}. The comparator has a small amount of hysteresis (typically 0.6mV) to prevent its output from oscillating at the crossover sense voltage. The ideal transfer characteristic of I_{OUT} (V_{OUT}) and the output of the comparator (SIGN) is shown in Figure 2.

The amplifier V_{OS} is only trimmed for the positive V_{SENSE} voltages ($V_{RS+} > V_{RS-}$). The SIGN comparator reconfigures the internal structure of the amplifier to work with negative V_{SENSE} voltages ($V_{RS-} > V_{RS+}$) and the precision V_{OS} trim is no longer effective and the resulting V_{OS} is slightly impacted. See details in the *Electrical Characteristics* Note 2. The user can choose the direction that needs the best precision to be the direction where $V_{RS+} > V_{RS-}$. For example, when monitoring Li+ battery currents, the discharge current should be $V_{RS+} > V_{RS-}$ to give the best accuracy over the largest dynamic range. When the battery charger is plugged in, the charge current flows in the opposite direction and is usually much larger, and a higher V_{OS} error can be tolerated. See the *Typical Operating Circuit*.

For applications with unidirectional currents (e.g., battery discharge only), the SIGN output can be ignored.

Note that as V_{SENSE} increases, the output current (I_{OUT} for the MAX9928 or V_{OUT}/10kΩ for the MAX9929) also increases. This additional current is supplied from V_{CC}.

-0.1V to +28V Input Range, Micropower, Uni-/Bidirectional, Current-Sense Amplifiers

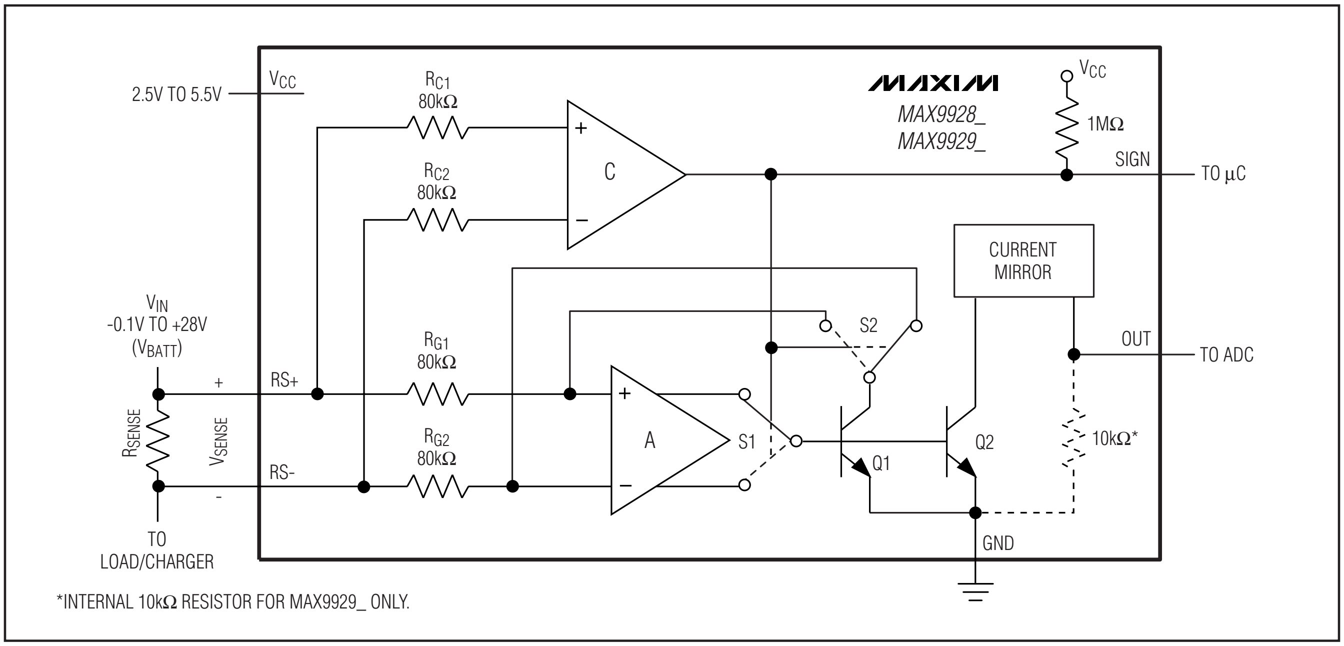


Figure 1. Functional Diagram

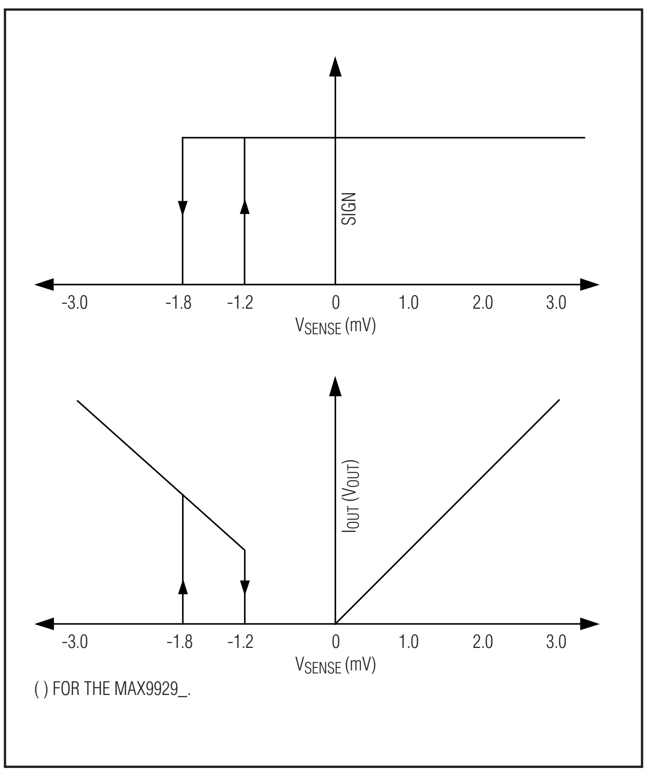


Figure 2. Ideal Transfer Characteristics with 0mV Amplifier Input Offset Voltage and -1mV Comparator Input Offset Voltage

For both positive and negative V_{SENSE} voltages, the current flowing out of the current mirror is equal to:

$$I_{OUT} = M \times |V_{SENSE}| / R_{G1}$$

For the MAX9928F/MAX9928T, the transconductance of the device is trimmed so that $I_{OUT}/|V_{SENSE}|$ = 5µA/mV and 2µA/mV, respectively. For the MAX9929F/MAX9929T, the voltage gain of the device is trimmed so that $V_{OUT}/|V_{SENSE}|$ = 50V/V and 20V/V, respectively. The SIGN output from the comparator indicates the polarity of V_{SENSE}.

Current Output (MAX9928_)

The output voltage equation for the MAX9928_ is given below:

$$V_{OUT} = (R_{SENSE} \times I_{LOAD}) \times (G_m \times R_{OUT})$$

where V_{OUT} = the desired full-scale output voltage, I_{LOAD} = the full-scale current being sensed, R_{SENSE} = the current-sense resistor, R_{OUT} = the voltage-setting resistor, and G_m = MAX9928F transconductance (5µA/mV) or MAX9928T transconductance (2µA/mV).

The full-scale output voltage range can be set by changing the R_{OUT} resistor value. The above equation can be modified to determine the R_{OUT} required for a particular full-scale range:

$$R_{OUT} = (V_{OUT})/(I_{LOAD} \times R_{SENSE} \times G_m)$$

OUT is a high-impedance current source and can drive an unlimited amount of capacitance.

Voltage Output (MAX9929_)

The output voltage equation for the MAX9929_ is given below:

$$V_{OUT} = (R_{SENSE} \times I_{LOAD}) \times (A_V)$$

where V_{OUT} = the desired full-scale output voltage, I_{LOAD} = the full-scale current being sensed, R_{SENSE} = the current-sense resistor, A_V = MAX9929F voltage gain (50V/V) or MAX9929T voltage gain = (20V/V).

SIGN Output

The current/voltage at OUT indicates magnitude. The SIGN output indicates the current's direction. The SIGN comparator compares RS+ to RS-. The sign output is high when RS+ is greater than RS- indicating positive current flow. The sign output is low when RS- is greater than RS+ indicating negative current flow. In battery-operated systems, this is useful for determining whether the battery is charging or discharging. The SIGN output might not correctly indicate the direction of load current when V_{SENSE} is between -1.8mV to -1.2mV (see Figure 2). Comparator hysteresis of 0.6mV prevents oscillation of SIGN output. If current direction is not needed, leave SIGN unconnected.

Applications Information

Choosing R_{SENSE}

The MAX9928_/MAX9929_ operate over a wide variety of current ranges with different sense resistors. Adjust the R_{SENSE} value to monitor higher or lower current levels. Select R_{SENSE} using these guidelines:

- **Voltage Loss:** A high R_{SENSE} value causes the power-source voltage to drop due to IR loss. For least voltage loss, use the lowest R_{SENSE} value.
- **Accuracy:** A high R_{SENSE} value allows lower currents to be measured more accurately. This is because offsets become less significant when the sense voltage is larger.
- **Efficiency and Power Dissipation:** At high current levels, the I^2R losses in R_{SENSE} might be significant. Take this into consideration when choosing the resistor value and power dissipation (wattage) rating. Also, if the sense resistor is allowed to heat up excessively, its value could drift.
- **Inductance:** If there is a large high-frequency component to I_{SENSE}, keep inductance low. Wire-wound resistors have the highest inductance, while metal film is somewhat better. Low-inductance metal-film resistors are available. Instead of being spiral wrapped around a core, as in metal film or wire-wound resistors, these are a straight band of metal. They are made in values under 1Ω.

Use in Systems with Super Capacitors

Since the input common-mode voltage range of the MAX9928/MAX9929 extends all the way from -0.1V to 28V, they are ideal to use in applications that require use of super capacitors for temporary or emergency energy storage systems. Some modern industrial and automotive systems use multifarad (1F–50F) capacitor banks to supply enough energy to keep critical systems alive even if the primary power source is removed or temporarily disabled. Unlike batteries, these capacitors can discharge all the way down to 0V. The MAX9928/MAX9929 can continuously help monitor their health and state of charge/discharge.

UCSP Applications Information

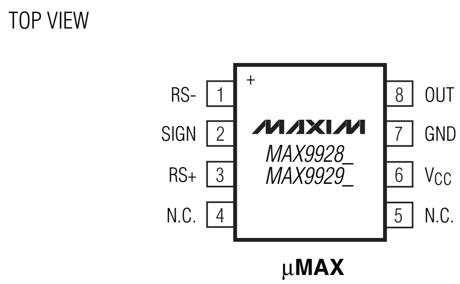
For the latest application details on UCSP construction, dimensions, tape carrier information, PCB techniques, bump-pad layout, and recommended reflow temperature profile, as well as the latest information on reliability testing results, go to Maxim's website at www.maxim-ic.com/ucsp to find Application Note 1891: *Understanding the Basics of the Wafer-Level Chip-Scale Package (WL-CSP).*

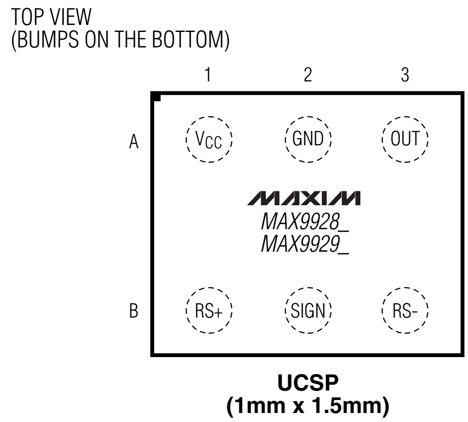
Chip Information

PROCESS: BiCMOS

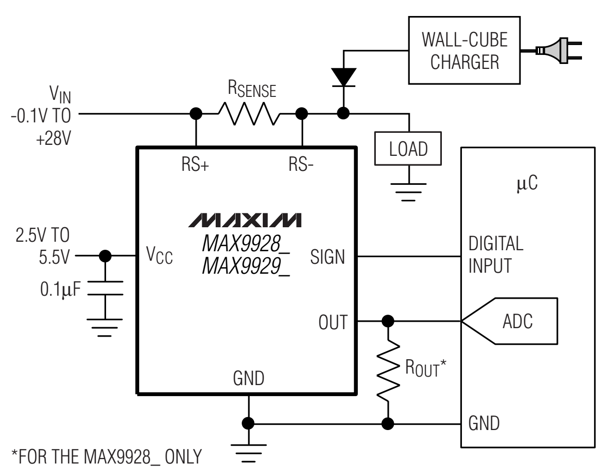
-0.1V to +28V Input Range, Micropower, Uni-/Bidirectional, Current-Sense Amplifiers

Pin Configurations



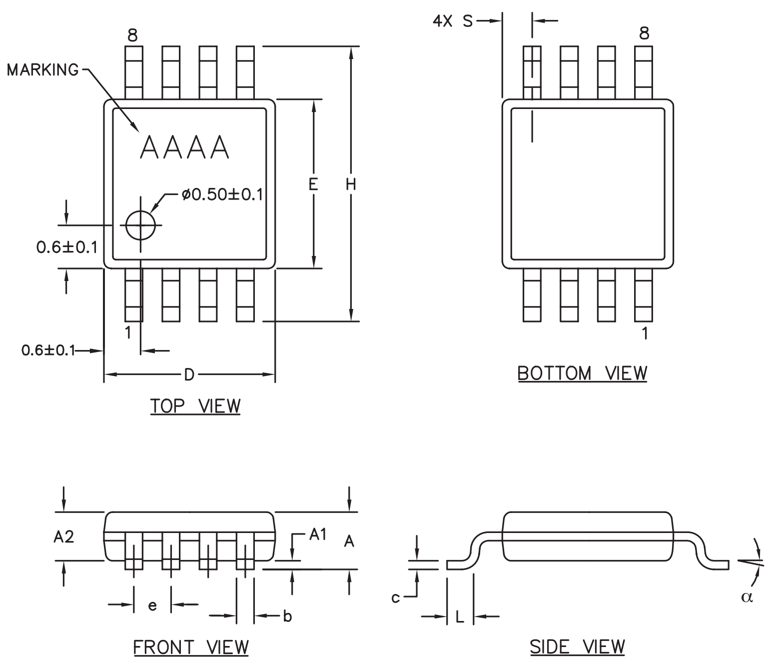


Typical Operating Circuit



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**.)



DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	–	0.043	–	1.10
A1	0.002	0.006	0.05	0.15
A2	0.030	0.037	0.75	0.95
b	0.010	0.014	0.25	0.36
c	0.005	0.007	0.13	0.18
D	0.116	0.120	2.95	3.05
e	0.0256 BSC		0.65 BSC	
E	0.116	0.120	2.95	3.05
H	0.188	0.198	4.78	5.03
L	0.016	0.026	0.41	0.66
α	0°	6°	0°	6°
S	0.0207 BSC		0.5250 BSC	

PKG. CODES:
U8–1; U8–3; U8C–3; U8CN–1

8LUMAXD.EPS

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED 0.15MM (.006").
3. CONTROLLING DIMENSION: MILLIMETERS.
4. COMPLIES TO JEDEC MO–187, LATEST REVISION, VARIATION AA.
5. MARKING SHOWN IS FOR PKG. ORIENTATION ONLY.
6. ALL DIMENSIONS APPLY TO BOTH LEADED (–) AND PbFREE (+) PKG. CODES.

–DRAWING NOT TO SCALE–

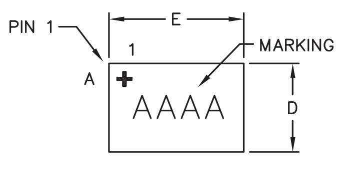
MAXIM

TITLE: PACKAGE OUTLINE, 8L uMAX/uSOP

APPROVAL	DOCUMENT CONTROL NO.	REV.	
	21–0036	K	1/1

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**.)

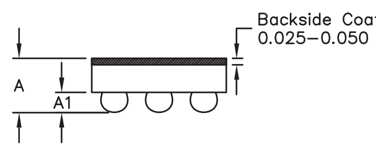


TOP VIEW

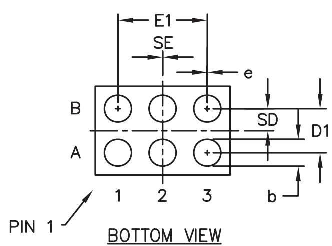
COMMON DIMENSIONS	
A	0.64±0.05
A1	0.24±0.03
b	ø0.30 REF
D1	0.50 BASIC
E1	1.00 BASIC
e	0.50 BASIC
SD	0.25 BASIC
SE	0.00 BASIC

PKG. CODE	VARIABLE DIMENSIONS		DEPOPULATED BUMPS
	E	D	
R61A1+1	1.52±0.05	1.00±0.05	NONE
R61B1+1	1.57±0.05	1.05±0.05	NONE
R61C1+1	1.57±0.05	1.16±0.05	NONE

UCSP.EPS



SIDE VIEW



BOTTOM VIEW

NOTES:
1. Terminal pitch is defined by terminal center to center value.
2. Outer dimension (D & E) is defined by center lines between scribe lines.
3. All dimensions in millimeters.
4. Marking shown is for package orientation reference only.
5. Tolerance is ± 0.02mm unless specified otherwise.
6. All dimensions apply to PbFree (+) package codes only.

–DRAWING NOT TO SCALE–

MAXIM

TITLE:
PACKAGE OUTLINE
6 BUMPS, 2x3 ARRAY, UCSP (R) PKG.

APPROVAL	DOCUMENT CONTROL NO.	REV.	
	21–0228	A	1/1

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