19-1380; Rev 2a; 12/99

MAXIM

Single/Dual/Quad, Low-Cost, SOT23, Low-Power, Rail-to-Rail I/O Op Amps

General Description

The MAX4322/MAX4323/MAX4326/MAX4327/MAX4329 family of operational amplifiers combines wide bandwidth and excellent DC accuracy with Rail-to-Rail® operation at the inputs and outputs. These devices require only 650µA per amplifier and operate from either a single supply (+2.4V to +6.5V) or dual supplies (±1.2V to ±3.25V). These unity-gain-stable amplifiers are capable of driving 250Ω loads and have a 5MHz gain-bandwidth product. The MAX4323 and MAX4327 feature a low-power shutdown mode that reduces supply current to 25µA and places the outputs in a high-impedance state.

With their rail-to-rail input common-mode range and output swing, these amplifiers are ideal for low-voltage, single-supply operation. In addition, low offset voltage and high speed make them the ideal signal-conditioning stages for precision, low-voltage data-acquisition systems. The MAX4322/MAX4323 are available in space-saving SOT23 packages.

Selector Guide

PART	BW (MHz)	NO. OF AMPS	PIN-PACKAGE	SHUTDOWN
MAX4322	5	1	5 SOT23-5, 8 µMAX/SO	—
MAX4323	5	1	8 µMAX/SO/ 6 SOT23-6	Yes
MAX4326	5	2	8 µMAX/SO	—
MAX4327	5	2	10 µMAX, 14 SO	Yes
MAX4329	5	4	14 SO	—

Applications

Battery-Powered Instruments
Portable Equipment
Data-Acquisition Systems
Signal Conditioning
Low-Power, Low-Voltage Applications

Pin Configurations appear at end of data sheet.

Rail-to-Rail is a registered trademark of Nippon Motorola, Ltd.

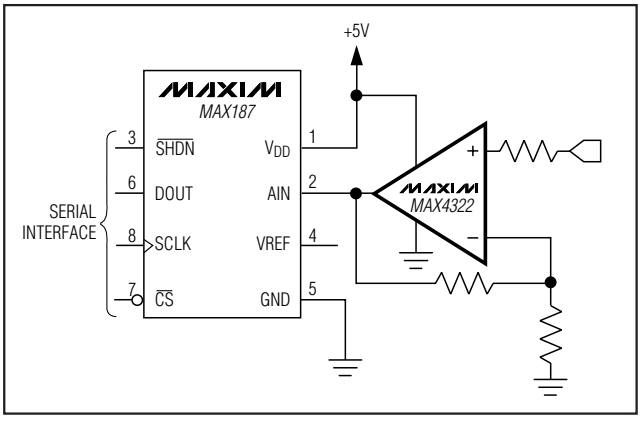
Features

- **SOT23 Packages (MAX4322/MAX4323)**
- **+2.4V to +6.5V Single-Supply Operation**
- **Rail-to-Rail Input Common-Mode Voltage Range**
- **Rail-to-Rail Output Voltage Swing**
- **5MHz Gain-Bandwidth Product**
- **650µA Quiescent Current per Amplifier**
- **700µV Offset Voltage**
- **No Phase Reversal for Overdriven Inputs**
- **Drive 250Ω Loads**
- **25µA Shutdown Mode (MAX4323/MAX4327)**
- **Unity-Gain Stable for Capacitive Loads up to 500pF**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE	TOP MARK
MAX4322EUK-T	-40°C to +85°C	5 SOT23-5	ACGE
MAX4322ESA	-40°C to +85°C	8 SO	—
MAX4322EUA	-40°C to +85°C	8 µMAX	—
MAX4323ESA	-40°C to +85°C	8 SO	—
MAX4323EUA	-40°C to +85°C	8 µMAX	—
MAX4323EUT	-40°C to +85°C	6 SOT23-6	AAEC
MAX4326EUA	-40°C to +85°C	8 µMAX	—
MAX4326ESA	-40°C to +85°C	8 SO	—
MAX4327EUB	-40°C to +85°C	10 µMAX	—
MAX4327ESD	-40°C to +85°C	14 SO	—
MAX4329ESD	-40°C to +85°C	14 SO	—

Typical Operating Circuit



Single/Dual/Quad, Low-Cost, SOT23, Low-Power, Rail-to-Rail I/O Op Amps

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V_{CC}-V_{EE}) .....+7.5V
All Other Pins .....(V_{CC} + 0.3V) to (V_{EE} - 0.3V)
Output Short-Circuit Duration.....Continuous
(short to either supply)
Continuous Power Dissipation (T_A = +70°C)
5-pin SOT23-5 (derate 7.1mW/°C above +70°C) 571mW
6-pin SOT23 (derate 7.1mW/°C Above + 70°C) 571mW
8-pin SO (derate 5.88mW/°C above +70°C).....471mW
8-pin µMAX (derate 4.10mW/°C above +70°C).....330mW
10-pin µMAX (derate 5.6mW/°C above +70°C).....444mW
14-pin SO (derate 8.00mW/°C above +70°C).....640mW

Operating Temperature Range
MAX432_E__ .....-40°C to +85°C
Maximum Junction Temperature .....+150°C
Storage Temperature Range .....-65°C to +160°C
Lead Temperature (soldering, 10sec) .....+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.

DC ELECTRICAL CHARACTERISTICS—T_A = +25°C

(V_{CC} = +5.0V, V_{EE} = 0, V_{CM} = 0, V_{OUT} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, R_L tied to V_{CC} / 2, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Input Offset Voltage	V_{CM} = V_{EE}, V_{CC}	MAX432_ESA/MAX4327ESD		±0.7	±2.0	mV
		All other packages		±1.2	±2.50	
Input Bias Current	V_{CM} = V_{EE}, V_{CC}			±50	±150	nA
Input Offset Current	V_{CM} = V_{EE}, V_{CC}			±1	±12	nA
Differential Input Resistance	-1.5V < V_{DIFF} < 1.5V			500		kΩ
Common-Mode Input Voltage Range	Inferred from CMRR test		V_{EE}		V_{CC}	V
Common-Mode Rejection Ratio	V_{EE} ≤ V_{CM} ≤ V_{CC}	MAX432_ESA/MAX4327ESD	62	94		dB
		All other packages	60	91		
Power-Supply Rejection Ratio	V_{CC} = 2.4V to 6.5V		66	100		dB
Output Resistance	A_V = +1V/V			0.1		Ω
Large-Signal Voltage Gain	V_{OUT} = 0.25V to 4.75V, R_L = 100kΩ			106		dB
	V_{OUT} = 0.4V to 4.6V, R_L = 250Ω		70	86		

DC ELECTRICAL CHARACTERISTICS—T_A = +25°C (continued)

(V_{CC} = +5V, V_{EE} = 0, V_{CM} = 0, V_{OUT} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, R_L tied to V_{CC} / 2, unless otherwise noted.)

PARAMETER	CONDITIONS			MIN	TYP	MAX	UNITS
Output Voltage Swing	MAX4322/ MAX4323	R_L = 100kΩ	V_{CC} - V_{OH}		12		mV
			V_{OL} - V_{EE}		20		
		R_L = 250Ω	V_{CC} - V_{OH}		200	300	
			V_{OL} - V_{EE}		100	200	
	MAX4326/ MAX4327/ MAX4329	R_L = 100kΩ	V_{CC} - V_{OH}		15		
			V_{OL} - V_{EE}		25		
		R_L = 250Ω	V_{CC} - V_{OH}		220	350	
			V_{OL} - V_{EE}		120	250	
Output Short-Circuit Current					50		mA
$\overline{SHDN}$ Logic Threshold	MAX4323/MAX4327		Low			0.8	V
			High	2.0			
$\overline{SHDN}$ Input Current	MAX4323/MAX4327				±1	±4	µA
Operating Supply-Voltage Range	Inferred from PSRR test			2.4		6.5	V
Supply Current per Amplifier	V_{CM} = V_{OUT} = V_{CC} / 2		V_{CC} = 2.4V		650		µA
			V_{CC} = 5V		725	1100	
Shutdown Supply Current per Amplifier	$\overline{SHDN}$ > 0.8V, MAX4323/MAX4327		V_{CC} = 2.4V		25		µA
			V_{CC} = 5V		40	60	

DC ELECTRICAL CHARACTERISTICS—T_A = -40°C to +85°C

(V_{CC} = +5V, V_{EE} = 0, V_{CM} = 0, V_{OUT} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, R_L tied to V_{CC} / 2, unless otherwise noted.) (Note 1)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Input Offset Voltage	V_{CM} = V_{EE}, V_{CC}	MAX432_ESA/MAX4327ESD			±3.0	mV
		All other packages			±6.0	
Input Offset Voltage Tempco				±2		µV/°C
Input Bias Current	V_{CM} = V_{EE}, V_{CC}				±180	nA
Input Offset Current	V_{CM} = V_{EE}, V_{CC}				±20	nA
Common-Mode Input Voltage Range	Inferred from CMRR test		V_{EE}		V_{CC}	V
Common-Mode Rejection Ratio	V_{EE} ≤ V_{CM} ≤ V_{CC}	MAX432_ESA/MAX4327ESD	59			dB
		All other packages	54			

Single/Dual/Quad, Low-Cost, SOT23, Low-Power, Rail-to-Rail I/O Op Amps

DC ELECTRICAL CHARACTERISTICS —T_A = -40°C to +85°C (continued)

(V_{CC} = +5V, V_{EE} = 0, V_{CM} = 0, V_{OUT} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, R_L tied to V_{CC} / 2, unless otherwise noted.) (Note 1)

PARAMETER	CONDITIONS			MIN	TYP	MAX	UNITS
Power-Supply Rejection Ratio	V_{CC} = 2.4V to 6.5V			62			dB
Large-Signal Voltage Gain	V_{OUT} = 0.4V to 4.6V, R_L = 250Ω			66			dB
Output Voltage Swing	MAX4322/ MAX4323	R_L = 250Ω	V_{CC} - V_{OH}			350	mV
			V_{OL} - V_{EE}			250	
	MAX4326/ MAX4327/ MAX4329	R_L = 250Ω	V_{CC} - V_{OH}			400	
			V_{OL} - V_{EE}			300	
$\overline{SHDN}$ Logic Threshold	MAX4323/MAX4327		Low			0.8	V
			High	2.0			
$\overline{SHDN}$ Input Current	MAX4323/MAX4327					±5	µA
Operating Supply-Voltage Range				2.4		6.5	V
Supply Current per Amplifier	V_{CM} = V_{CC} / 2					1.2	mA
Shutdown Supply Current per Amplifier	$\overline{SHDN}$ ≤ 0.8V, MAX4323/MAX4327					70	µA

AC ELECTRICAL CHARACTERISTICS

(V_{CC} = +5V, V_{EE} = 0, V_{CM} = V_{OUT} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, T_A = +25°C unless otherwise noted.)

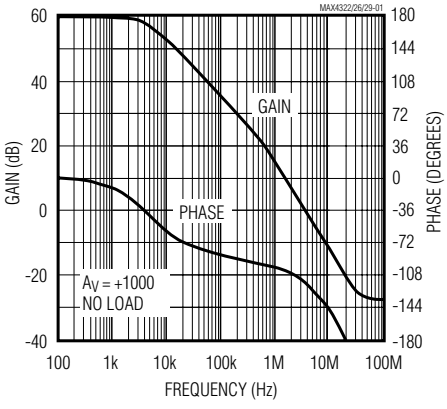
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Gain-Bandwidth Product				5		MHz
Phase Margin				64		degrees
Gain Margin				12		dB
Total Harmonic Distortion	f = 10kHz, V_{OUT} = 2Vp-p, A_V = +1V/V			0.003		%
Slew Rate				2		V/µs
Settling Time to 0.01%	A_V = +1V/V, V_{OUT} = 2V step			2.0		µs
Turn-On Time	V_{CC} = 0 to 3V step			1		µs
$\overline{SHDN}$ Delay	MAX4323/MAX4327	Enable		1		µs
		Disable		0.2		
Input Capacitance				3		pF
Input Noise Voltage Density	f = 1kHz			22		nV/√Hz
Input Noise Current Density	f = 1kHz			0.4		pA
Amp-Amp Isolation				135		dB
Capacitive Load Stability	A_V = +1V/V			250		pF

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

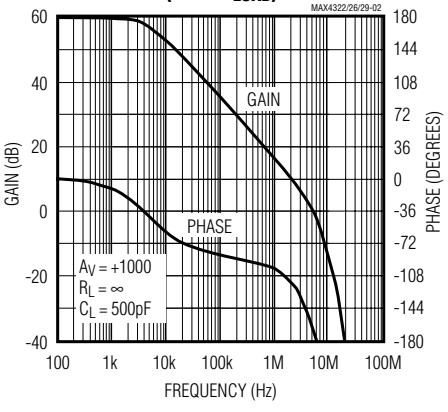
Typical Operating Characteristics

(V_{CC} = +5V, V_{EE} = 0, V_{CM} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, T_A = +25°C, unless otherwise noted.)

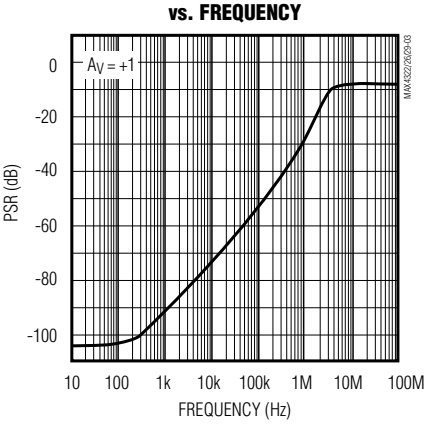
GAIN AND PHASE vs. FREQUENCY



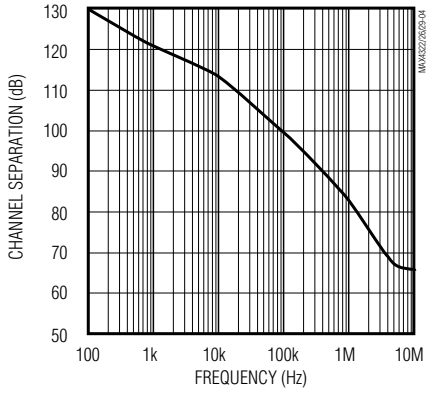
GAIN AND PHASE vs. FREQUENCY (WITH C_{LOAD})



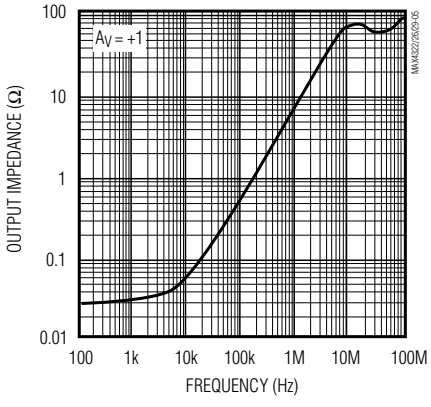
POWER-SUPPLY REJECTION vs. FREQUENCY



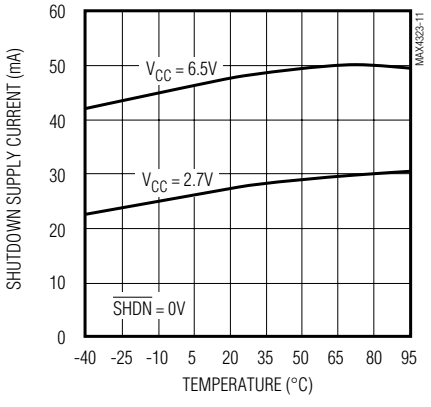
MAX4326/MAX4327/MAX4329 CHANNEL SEPARATION vs. FREQUENCY



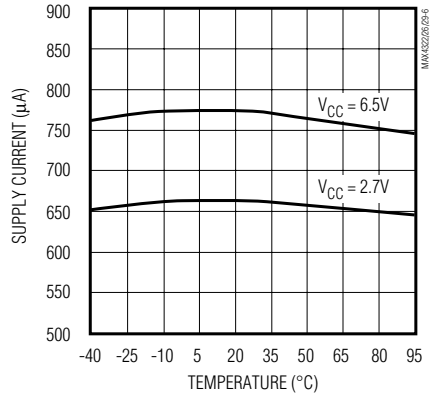
OUTPUT IMPEDANCE vs. FREQUENCY



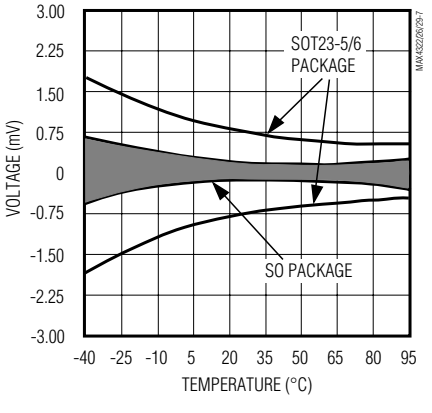
MAX4323/MAX4327 SHUTDOWN SUPPLY CURRENT vs. TEMPERATURE



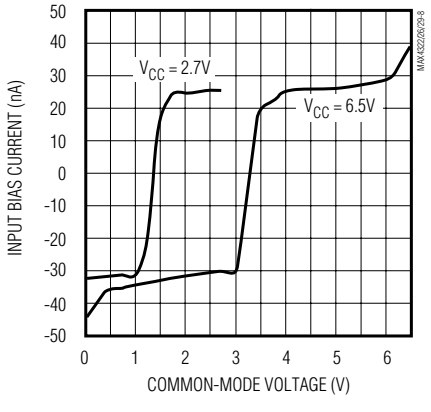
SUPPLY CURRENT PER AMPLIFIER vs. TEMPERATURE



INPUT OFFSET VOLTAGE vs. TEMPERATURE



INPUT BIAS CURRENT vs. COMMON-MODE VOLTAGE

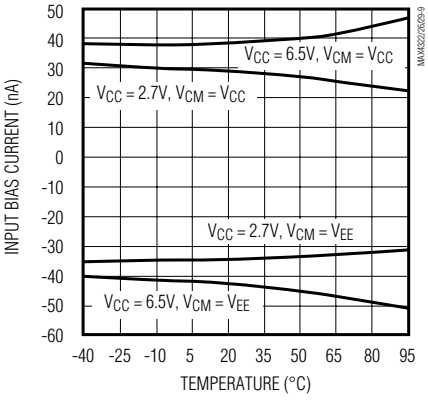


Single/Dual/Quad, Low-Cost, SOT23, Low-Power, Rail-to-Rail I/O Op Amps

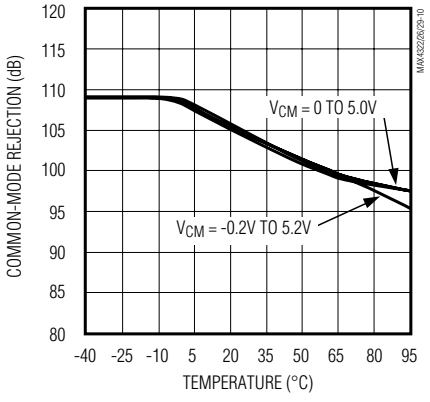
Typical Operating Characteristics (continued)

(V_{CC} = +5V, V_{EE} = 0, V_{CM} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, T_A = +25°C, unless otherwise noted.)

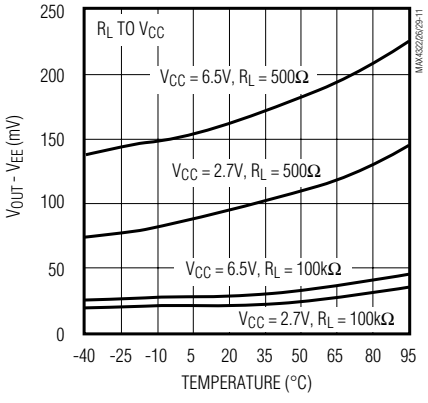
INPUT BIAS CURRENT vs. TEMPERATURE



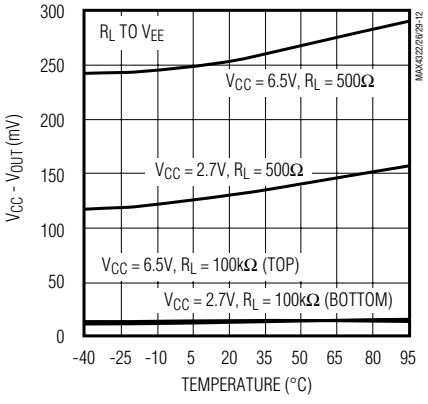
COMMON-MODE REJECTION vs. TEMPERATURE



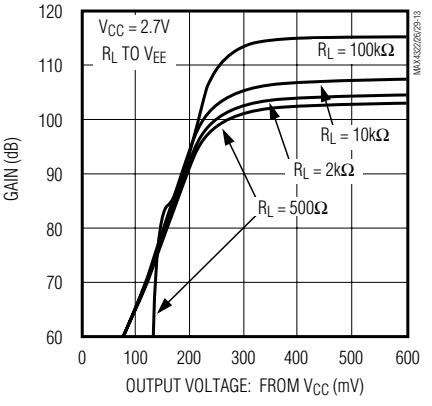
MINIMUM OUTPUT VOLTAGE vs. TEMPERATURE



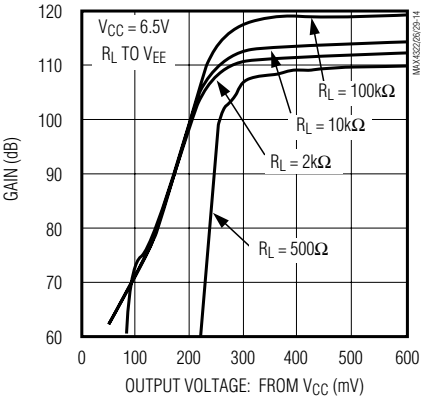
MAXIMUM OUTPUT VOLTAGE vs. TEMPERATURE



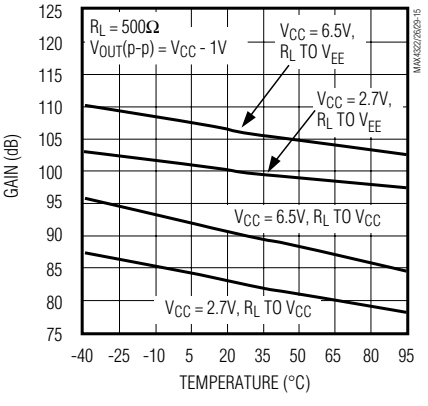
LARGE-SIGNAL GAIN vs. OUTPUT VOLTAGE



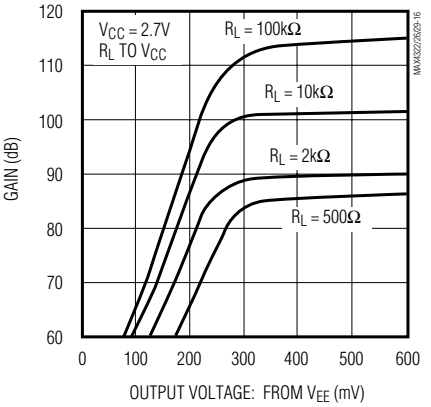
LARGE-SIGNAL GAIN vs. OUTPUT VOLTAGE



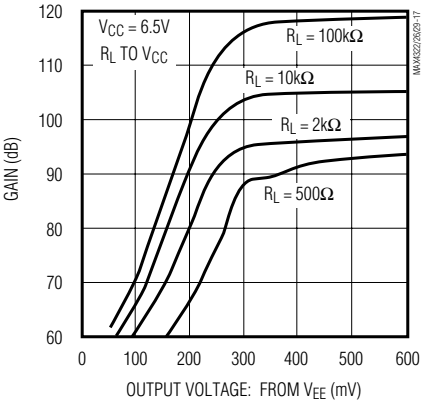
LARGE-SIGNAL GAIN vs. TEMPERATURE



LARGE-SIGNAL GAIN vs. OUTPUT VOLTAGE



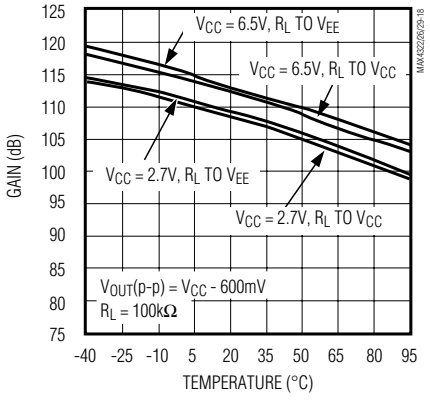
LARGE-SIGNAL GAIN vs. OUTPUT VOLTAGE



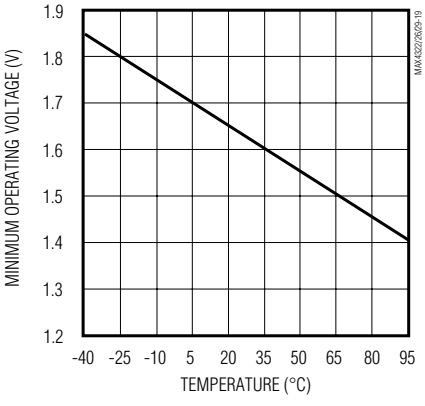
Typical Operating Characteristics (continued)

(V_{CC} = +5V, V_{EE} = 0, V_{CM} = V_{CC} / 2, $\overline{SHDN}$ = V_{CC}, T_A = +25°C, unless otherwise noted.)

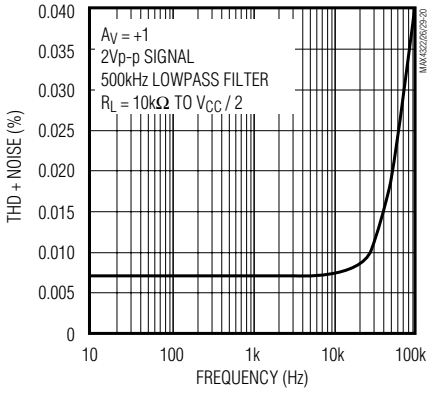
LARGE-SIGNAL GAIN vs. TEMPERATURE



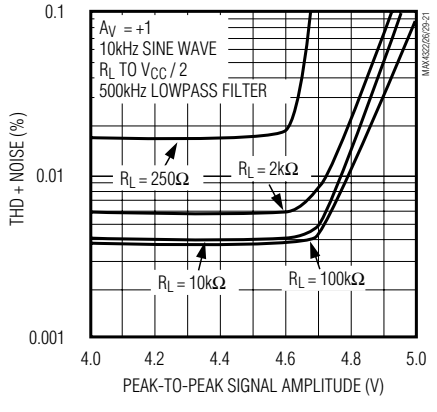
MINIMUM OPERATING VOLTAGE vs. TEMPERATURE



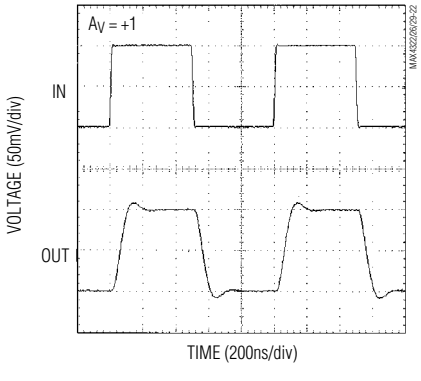
TOTAL HARMONIC DISTORTION AND NOISE vs. FREQUENCY



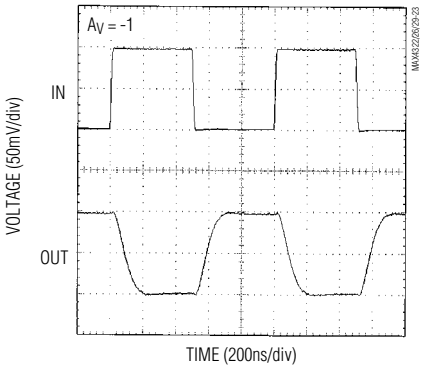
TOTAL HARMONIC DISTORTION AND NOISE vs. PEAK-TO-PEAK SIGNAL AMPLITUDE



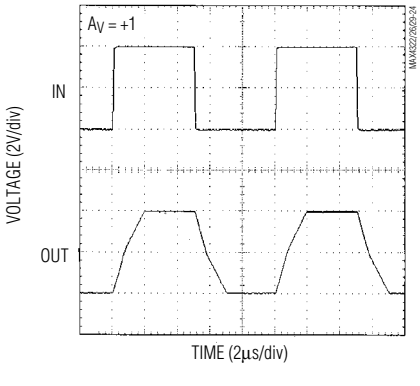
SMALL-SIGNAL TRANSIENT RESPONSE (NONINVERTING)



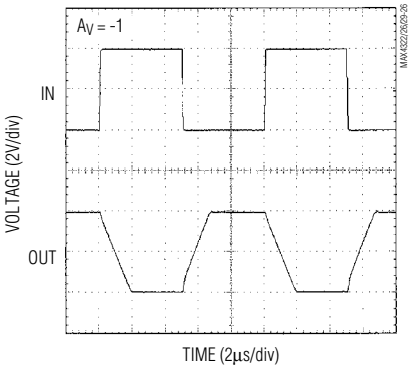
SMALL-SIGNAL TRANSIENT RESPONSE (INVERTING)



LARGE-SIGNAL TRANSIENT RESPONSE (NONINVERTING)



LARGE-SIGNAL TRANSIENT RESPONSE (INVERTING)



Single/Dual/Quad, Low-Cost, SOT23, Low-Power, Rail-to-Rail I/O Op Amps

Pin Description

PIN								NAME	FUNCTION
MAX4322		MAX4323		MAX4326	MAX4327		MAX4329		
SOT23-5	SO/µMAX	SOT23-6	SO/µMAX		µMAX	SO			
1	6	1	6	—	—	—	—	OUT	Output
2	4	2	4	4	4	4	11	V_{EE}	Negative Supply. Ground for single-supply operation.
3	—	3	—	—	—	—	—	IN+	Noninverting Input
4	—	4	—	—	—	—	—	IN-	Inverting Input
5	7	6	7	8	10	14	4	V_{CC}	Positive Supply
—	1, 5, 8	—	1, 5	—	—	5, 7, 8, 10	—	N.C.	No Connection
—	—	5	8	—		—	—	$\overline{SHDN}$	Shutdown Control. Tie high or leave floating to enable amplifier.
—	—	—	—	1, 7	1, 9	1, 13	1, 7	OUT1, OUT2	Outputs for amps 1 and 2
—	2	—	2	2, 6	2, 8	2, 12	2, 6	IN1-, IN2-	Inverting Inputs for amps 1 and 2
—	3	—	3	3, 5	3, 7	3, 11	3, 5	IN1+, IN2+	Noninverting Inputs for amps 1 and 2
—	—	—	—	—	5, 6	5, 9	—	$\overline{SHDN1}$, $\overline{SHDN2}$	Shutdown Control for amps 1 and 2. Tie high or leave floating to enable amplifier.
—	—	—	—	—	—	—	8, 14	OUT3, OUT4	Outputs for amps 3 and 4
—	—	—	—	—	—	—	9, 13	IN3-, IN4-	Inverting Inputs for amps 3 and 4
—	—	—	—	—	—	—	10, 12	IN3+, IN4+	Noninverting Inputs for amps 3 and 4

Applications Information

Rail-to-Rail Input Stage

Devices in the MAX4322/MAX4323/MAX4326/MAX4327/MAX4329 family of high-speed amplifiers have rail-to-rail input and output stages designed for low-voltage, single-supply operation. The input stage consists of separate NPN and PNP differential stages, which combine to provide an input common-mode range extending to the supply rails. The PNP stage is active for input voltages close to the negative rail, and the NPN stage is active for input voltages near the positive rail. The input offset voltage is typically below 250µV. The switchover transition region, which occurs near V_{CC} / 2, has been extended to minimize the slight degradation in CMRR caused by the mismatch of the input pairs. Their low offset voltage, high bandwidth, and rail-to-rail common-mode range make these op amps excellent choices for precision, low-voltage, data-acquisition systems.

Since the input stage switches between the NPN and PNP pairs, the input bias current changes polarity as the input voltage passes through the transition region. To reduce the offset error caused by input bias currents flowing through external source impedances, match the effective impedance seen by each input (Figures 1a, 1b). High source impedances, together

with the input capacitance, can create a parasitic pole that produces an underdamped signal response. Reducing the input impedance or placing a small (2pF to 10pF) capacitor across the feedback resistor improves the response.

The MAX4322/MAX4323/MAX4326/MAX4327/MAX4329's inputs are protected from large differential input voltages by 1kΩ series resistors and back-to-back triple diodes across the inputs (Figure 2). For differential input voltages less than 1.8V the input resistance is typically 500kΩ. For differential input voltages greater than 1.8V the input resistance is approximately 2kΩ, and the input bias current is determined by the following equation:

$$I_{BIAS} = \frac{V_{DIFF} - 1.8V}{2k\Omega}$$

Rail-to-Rail Output Stage

The minimum output voltage will be within millivolts of ground for single-supply operation where the load is referenced to ground (V_{EE}). Figure 3 shows the input voltage range and output voltage swing of a MAX4322 connected as a voltage follower. With a +3V supply and the load tied to ground, the output swings from 0.00V to 2.90V. The maximum output voltage swing depends on the load, but will be within 350mV of a +5V supply, even with the maximum load (500Ω to ground).

Driving a capacitive load can cause instability in most high-speed op amps, especially those with low quiescent current. The MAX4322/MAX4323/MAX4326/MAX4327/MAX4329 have a high tolerance for capacitive loads. They are stable with capacitive loads up to 500pF. Figure 4 gives the stable operating region for capacitive loads. Figures 5 and 6 show the response with capacitive loads and the results of adding an isolation resistor in series with the output (Figure 7). The resistor improves the circuit's phase margin by isolating the load capacitor from the op amp's output.

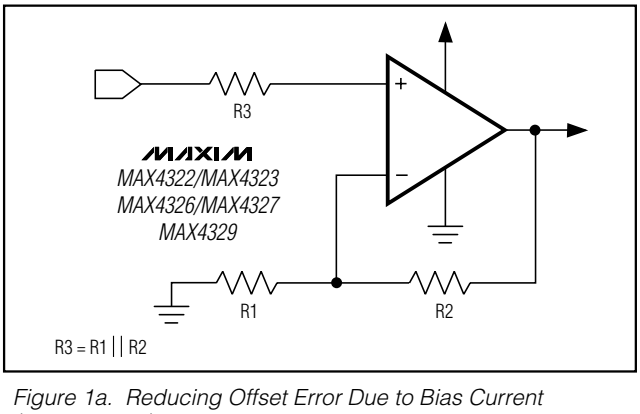


Figure 1a. Reducing Offset Error Due to Bias Current (Noninverting)

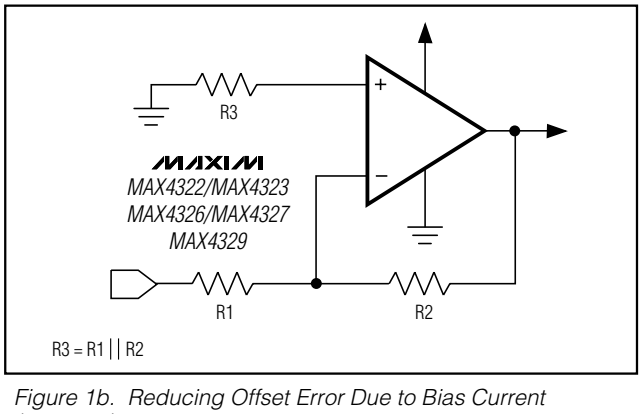


Figure 1b. Reducing Offset Error Due to Bias Current (Inverting)

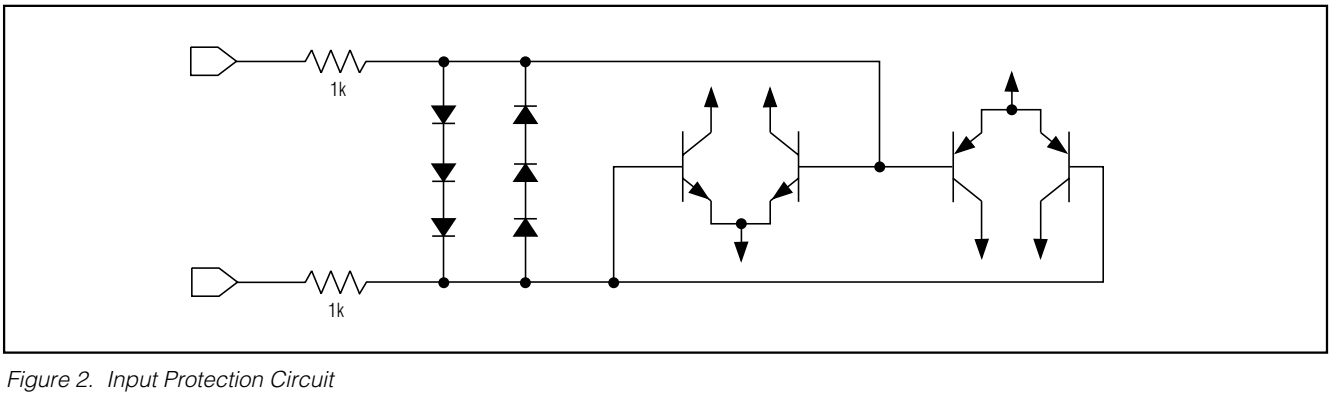


Figure 2. Input Protection Circuit

Single/Dual/Quad, Low-Cost, SOT23, Low-Power, Rail-to-Rail I/O Op Amps

Power-Up and Shutdown Mode

The MAX4322/MAX4323/MAX4326/MAX4327/MAX4329 amplifiers typically settle within 1µs after power-up. Using the test circuit of Figure 8, Figures 9 and 10 show the output voltage and supply current on power-up.

The MAX4323 and MAX4327 have a shutdown option. When the shutdown pin ($\overline{SHDN}$) is pulled low, the supply current drops below 25µA per amplifier and the amplifiers are disabled with the outputs in a high-impedance state. Pulling $\overline{SHDN}$ high or leaving it floating enables the amplifier. In the dual-amplifier MAX4327, the shutdown functions operate independently. Figures 11 and 12 show the output voltage and supply current responses of the MAX4323 to a shutdown pulse.

Power Supplies and Layout

The MAX4322/MAX4323/MAX4326/MAX4327/MAX4329 operate from a single +2.4V to +6.5V power supply, or from dual supplies of ±1.2V to ±3.25V. For single-supply operation, bypass the power supply with a 0.1µF ceramic capacitor in parallel with at least 1µF. For dual supplies, bypass each supply to ground.

Good layout improves performance by decreasing the amount of stray capacitance at the op amp's inputs and outputs. To decrease stray capacitance, minimize trace lengths and resistor leads by placing external components close to the op amp's pins.

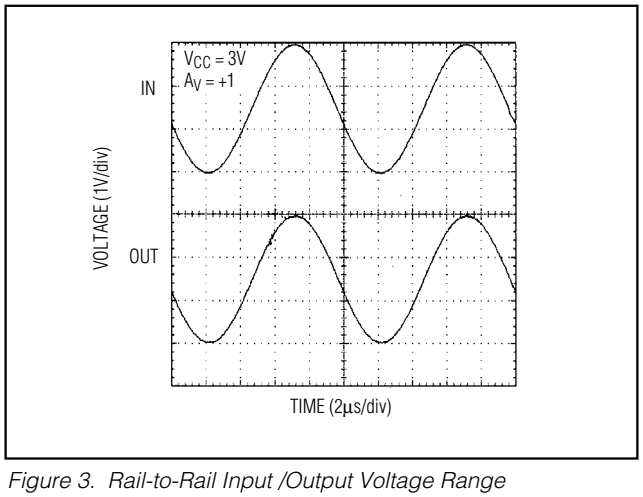


Figure 3. Rail-to-Rail Input /Output Voltage Range

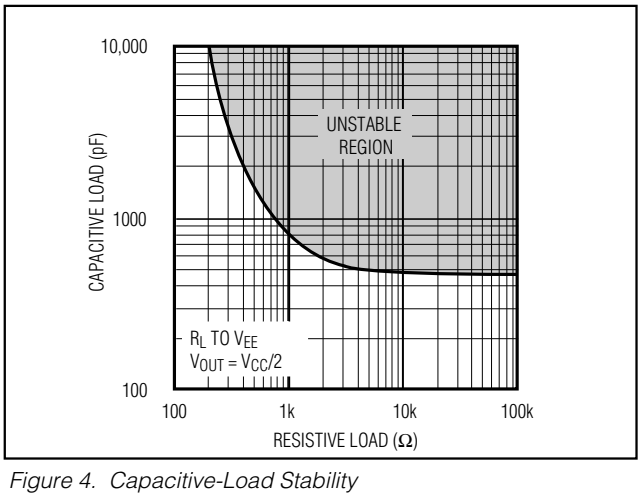


Figure 4. Capacitive-Load Stability

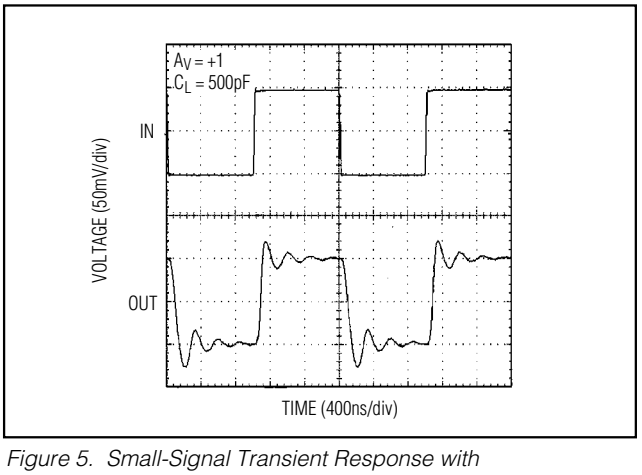


Figure 5. Small-Signal Transient Response with Capacitive Load

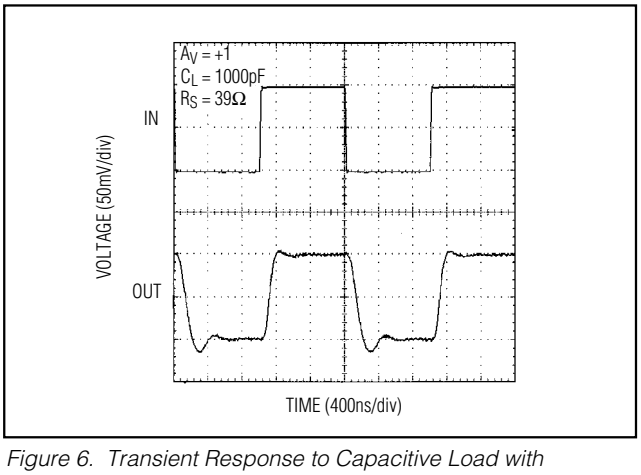


Figure 6. Transient Response to Capacitive Load with Isolation Resistor

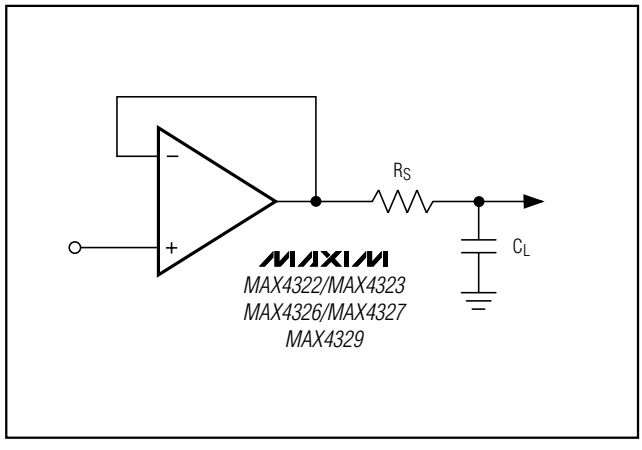


Figure 7. Capacitive-Load-Driving Circuit

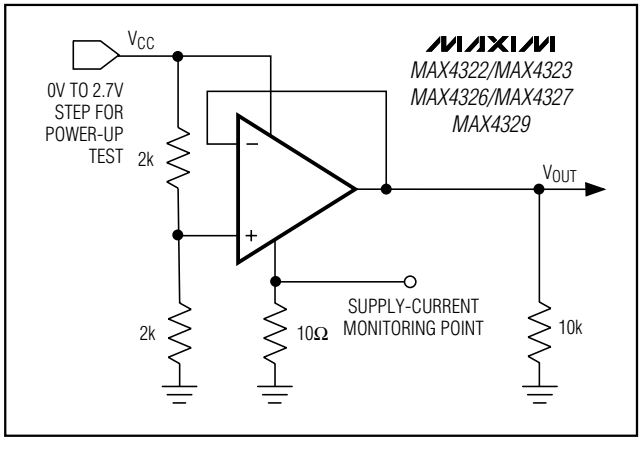


Figure 8. Power-Up Test Circuit

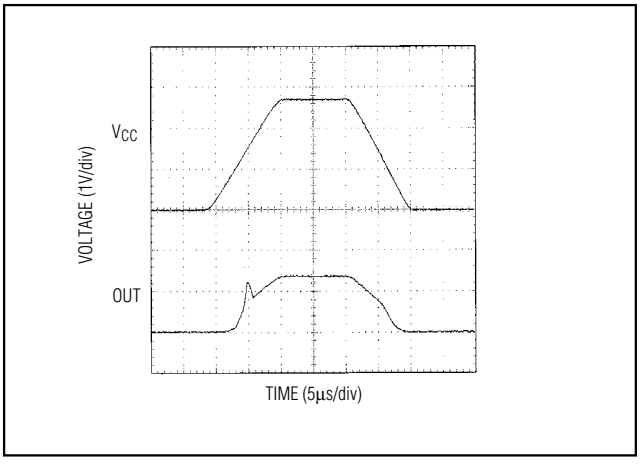


Figure 9. Power-Up Output Voltage

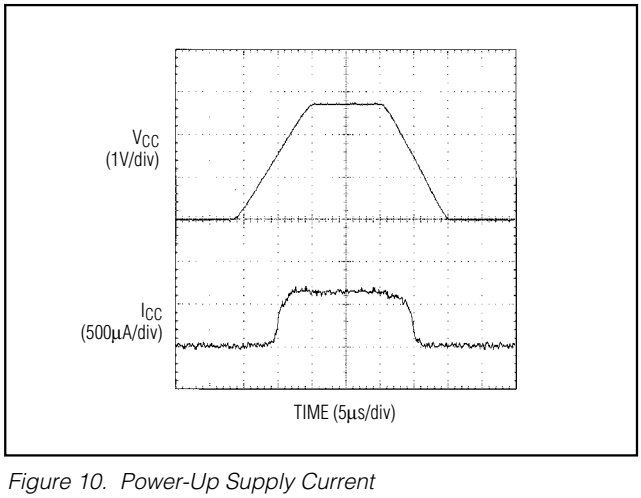


Figure 10. Power-Up Supply Current

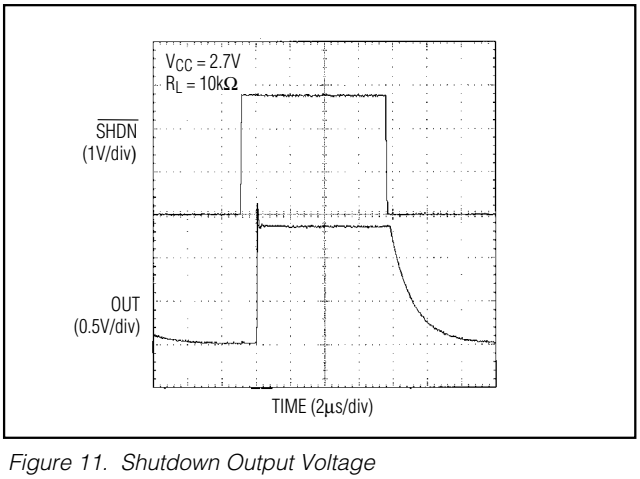


Figure 11. Shutdown Output Voltage

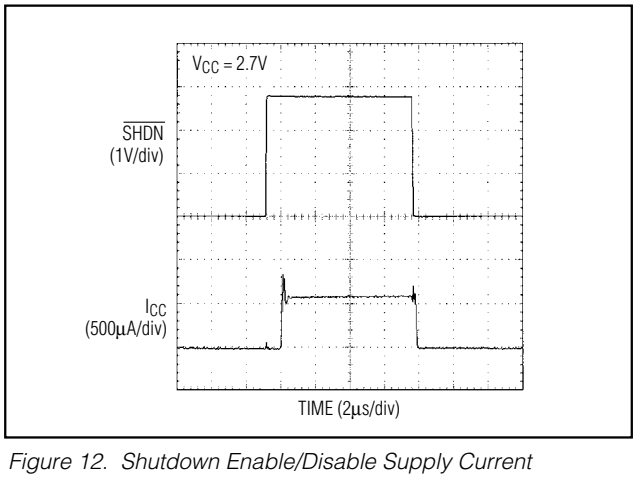
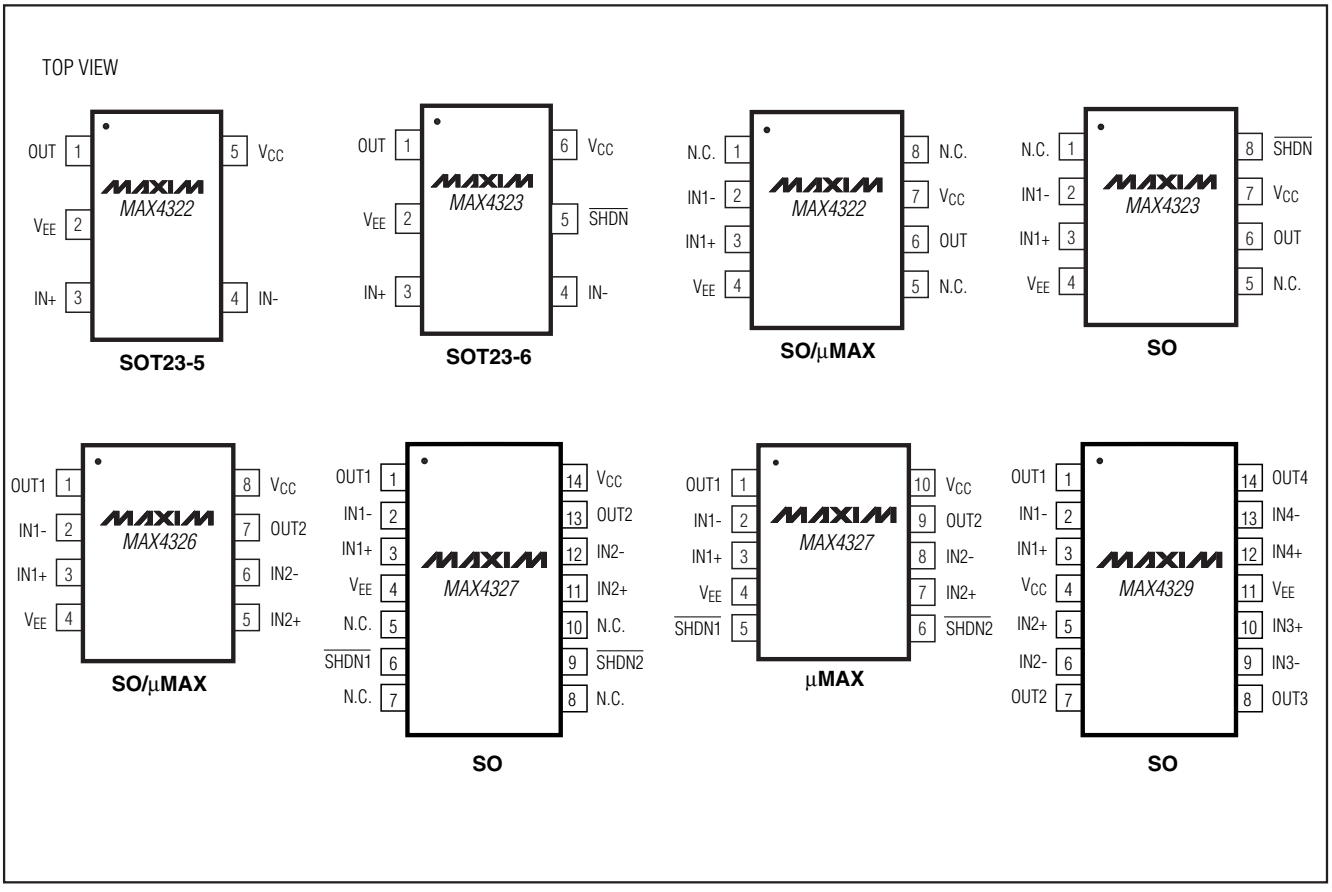


Figure 12. Shutdown Enable/Disable Supply Current

Single/Dual/Quad, Low-Cost, SOT23, Low-Power, Rail-to-Rail I/O Op Amps

Pin Configurations



Chip Information

MAX4322 TRANSISTOR COUNT: 170
MAX4323 TRANSISTOR COUNT: 170
MAX4326 TRANSISTOR COUNT: 340
MAX4327 TRANSISTOR COUNT: 340
MAX4329 TRANSISTOR COUNT: 680

SUBSTRATE CONNECTED TO V_{EE}