ANALOG DEVICES

16 V Auto-Zero, Rail-to-Rail Output Operational Amplifier

AD8638

FEATURES

Low offset voltage: 9 μV maximum
Offset drift: 0.04 μV/°C
Rail-to-rail output swing
+16 V single- or ±8 V dual-supply operation
High gain and CMRR: 133 dB typical
High PSRR: 143 dB typical
Very low input bias current: 40 pA
Low supply current: 1.3 mA

APPLICATIONS

Pressure and position sensors
Strain gage amplifiers
Medical instrumentation
Thermocouple amplifiers
Automotive sensors
Precision references
Precision current sensing

PIN CONFIGURATIONS

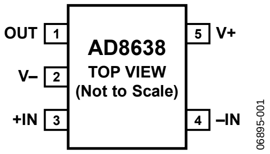

Figure 1. 5-Lead SOT-23 (RJ-5)

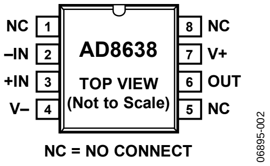

Figure 2. 8-Lead SOIC_N (R-8)

GENERAL DESCRIPTION

The AD8638 is a wide bandwidth, auto-zero amplifier featuring rail-to-rail output swing and low noise. This amplifier has very low offset, drift, and bias current. Operation is fully specified from 5 V to 16 V single supply (±2.5 V to ±8 V dual supply).

The AD8638 provides benefits previously found only in expensive zero-drift or chopper-stabilized amplifiers. Using the Analog Devices, Inc., topology, these auto-zero amplifiers combine low cost with high accuracy and low noise. No external capacitors are required. In addition, the AD8638 greatly reduces the digital switching noise found in most chopper-stabilized amplifiers.

With a typical offset voltage of only 3 μV, drift of less than 0.04 μV/°C, and noise of only 1.2 μV p-p (0.1 Hz to 10 Hz), the AD8638 is suited for applications in which error sources cannot be tolerated. Position and pressure sensors, medical equipment, and strain gage amplifiers benefit greatly from nearly zero drift over their operating temperature ranges. Many systems can take advantage of the rail-to-rail output swing provided by the AD8638 to maximize SNR.

The AD8638 is specified for the extended industrial temperature range (−40°C to +125°C). The AD8638 is available in tiny 5-lead SOT-23 and 8-lead SOIC packages.

The AD8638 is a member of a growing series of auto-zero op amps offered by Analog Devices (see Table 1).

Table 1. Auto-Zero Op Amps

Supply	5 V	5 V Low Power	16 V
Single	AD8628	AD8538	AD8638
Dual	AD8629	AD8539	
Quad	AD8630		

Rev. A

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11/07—Revision 0: Initial Version

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS—5 V OPERATION

V_{SY} = 5 V, V_{CM} = 2.5 V, T_A = 25°C, unless otherwise noted.

Table 2.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
Offset Voltage	V_{OS}			3	9	µV
		−40°C ≤ T_A ≤ +125°C			23	µV
		−0.1 V ≤ V_{CM} ≤ +3.0 V		3	9	µV
		−40°C ≤ T_A ≤ +125°C			23	µV
Input Bias Current	I_B			1.5	40	pA
		−40°C ≤ T_A ≤ +85°C		7	40	pA
		−40°C ≤ T_A ≤ +125°C		45	105	pA
Input Offset Current	I_{OS}			7	40	pA
		−40°C ≤ T_A ≤ +85°C		7	40	pA
		−40°C ≤ T_A ≤ +125°C		16.5	60	pA
Input Voltage Range		−40°C ≤ T_A ≤ +125°C	−0.1		+3	V
Common-Mode Rejection Ratio	CMRR	V_{CM} = 0 V to 3 V	118	133		dB
		−40°C ≤ T_A ≤ +125°C	118			dB
Large Signal Voltage Gain	A_{VO}	R_L = 10 kΩ, V_O = 0.5 V to 4.5 V	120	136		dB
		−40°C ≤ T_A ≤ +125°C	119			dB
Offset Voltage Drift for SOIC	$\Delta V_{OS}/\Delta T$	−40°C ≤ T_A ≤ +125°C		0.01	0.04	µV/°C
Offset Voltage Drift for SOT-23	$\Delta V_{OS}/\Delta T$	−40°C ≤ T_A ≤ +125°C		0.04	0.15	µV/°C
OUTPUT CHARACTERISTICS						
Output Voltage High	V_{OH}	R_L = 10 kΩ to V_{CM}	4.97	4.985		V
		−40°C ≤ T_A ≤ +125°C	4.97			V
		R_L = 2 kΩ to V_{CM}	4.90	4.93		V
		−40°C ≤ T_A ≤ +125°C	4.86			V
Output Voltage Low	V_{OL}	R_L = 10 kΩ to V_{CM}		7.5	10	mV
		−40°C ≤ T_A ≤ +125°C			15	mV
		R_L = 2 kΩ to V_{CM}		32	40	mV
		−40°C ≤ T_A ≤ +125°C			55	mV
Short-Circuit Current	I_{SC}	T_A = 25°C		±19		mA
Closed-Loop Output Impedance	Z_{OUT}	f = 100 kHz, A_V = 1		4.2		Ω
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	V_{SY} = 4.5 V to 16 V	127	143		dB
		−40°C ≤ T_A ≤ +125°C	125			dB
Supply Current/Amplifier	I_{SY}	I_O = 0 mA		1.0	1.3	mA
		−40°C ≤ T_A ≤ +125°C			1.5	mA
DYNAMIC PERFORMANCE						
Slew Rate	SR	R_L = 10 kΩ		2.5		V/µs
Settling Time to 0.1%	t_s	2 V step, C_L = 20 pF, R_L = 1 kΩ		3		µs
Overload Recovery Time				50		µs
Gain Bandwidth Product	GBP	R_L = 2 kΩ, C_L = 20 pF		1.35		MHz
Phase Margin	Φ_M	R_L = 2 kΩ, C_L = 20 pF		70		Degrees
NOISE PERFORMANCE						
Voltage Noise	e_n p-p	0.1 Hz to 10 Hz		1.2		µV p-p
Voltage Noise Density	e_n	f = 1 kHz		60		nV/√Hz

ELECTRICAL CHARACTERISTICS—16 V OPERATION

V_{SY} = 16 V, V_{CM} = 8 V, T_A = 25°C, unless otherwise noted.

Table 3.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
Offset Voltage	V_{OS}			3	9	μV
		−40°C ≤ T_A ≤ +125°C			23	μV
		−0.1 V ≤ V_{CM} ≤ +14 V		3	9	μV
		−40°C ≤ T_A ≤ +125°C			23	μV
Input Bias Current	I_B			1	75	pA
		−40°C ≤ T_A ≤ +85°C		4	75	pA
		−40°C ≤ T_A ≤ +125°C		85	250	pA
Input Offset Current	I_{OS}			20	70	pA
		−40°C ≤ T_A ≤ +85°C		20	75	pA
		−40°C ≤ T_A ≤ +125°C		50	150	pA
Input Voltage Range		−40°C ≤ T_A ≤ +125°C	−0.1		+14	V
Common-Mode Rejection Ratio	CMRR	V_{CM} = 0 V to 14 V	127	142		dB
		−40°C ≤ T_A ≤ +125°C	127			dB
Large Signal Voltage Gain	A_{VO}	R_L = 10 kΩ, V_O = 0.5 V to 15.5 V	130	147		dB
		−40°C ≤ T_A ≤ +125°C	130			dB
Offset Voltage Drift for SOIC	$\Delta V_{OS}/\Delta T$	−40°C ≤ T_A ≤ +125°C		0.03	0.06	μV/°C
Offset Voltage Drift for SOT-23	$\Delta V_{OS}/\Delta T$	−40°C ≤ T_A ≤ +125°C		0.04	0.15	μV/°C
OUTPUT CHARACTERISTICS						
Output Voltage High	V_{OH}	R_L = 10 kΩ to V_{CM}	15.94	15.96		V
		−40°C ≤ T_A ≤ +125°C	15.93			V
		R_L = 2 kΩ to V_{CM}	15.77	15.82		V
		−40°C ≤ T_A ≤ +125°C	15.70			V
Output Voltage Low	V_{OL}	R_L = 10 kΩ to V_{CM}		30	40	mV
		−40°C ≤ T_A ≤ +125°C			60	mV
		R_L = 2 kΩ to V_{CM}		110	130	mV
		−40°C ≤ T_A ≤ +125°C			190	mV
Short-Circuit Current	I_{SC}	T_A = 25°C		±37		mA
Closed-Loop Output Impedance	Z_{OUT}	f = 100 kHz, A_V = 1		3.0		Ω
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	V_{SY} = 4.5 V to 16 V	127	143		dB
		−40°C ≤ T_A ≤ +125°C	125			dB
Supply Current/Amplifier	I_{SY}	I_O = 0 mA		1.25	1.5	mA
		−40°C ≤ T_A ≤ +125°C			1.7	mA
DYNAMIC PERFORMANCE						
Slew Rate	SR	R_L = 10 kΩ		2		V/μs
Settling Time to 0.1%	t_s	4 V step, C_L = 20 pF, R_L = 1 kΩ		4		μs
Overload Recovery Time				50		μs
Gain Bandwidth Product	GBP			1.5		MHz
Phase Margin	Φ_M			74		Degrees
NOISE PERFORMANCE						
Voltage Noise	e_n p-p	0.1 Hz to 10 Hz		1.2		μV p-p
Voltage Noise Density	e_n	f = 1 kHz		60		nV/√Hz

ABSOLUTE MAXIMUM RATINGS

Table 4.

Parameter	Rating
Supply Voltage	16 V
Input Voltage	GND − 0.3 V to V_{SY+} + 0.3 V
Differential Input Voltage[1]	±Supply voltage
Output Short-Circuit Duration to GND	Indefinite
Storage Temperature Range	
R and RJ Packages	−65°C to +150°C
Operating Temperature Range	−40°C to +125°C
Junction Temperature Range	
R and RJ Packages	−65°C to +150°C
Lead Temperature (Soldering, 60 sec)	300°C

[1] Because there are 1 kΩ resistors and back-to-back protection diodes on the input, when the differential voltage is greater than 0.7 V, the apparent input bias current increases.

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

THERMAL RESISTANCE

θ_{JA} is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages. This was measured using a standard 2-layer board.

Table 5. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
5-Lead SOT-23 (RJ-5)	230	146	°C/W
8-Lead SOIC_N (R-8)	158	43	°C/W

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

TYPICAL PERFORMANCE CHARACTERISTICS

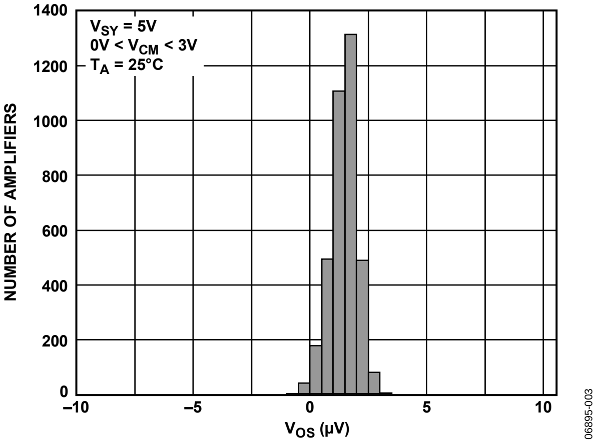

Figure 3. Input Offset Voltage Distribution

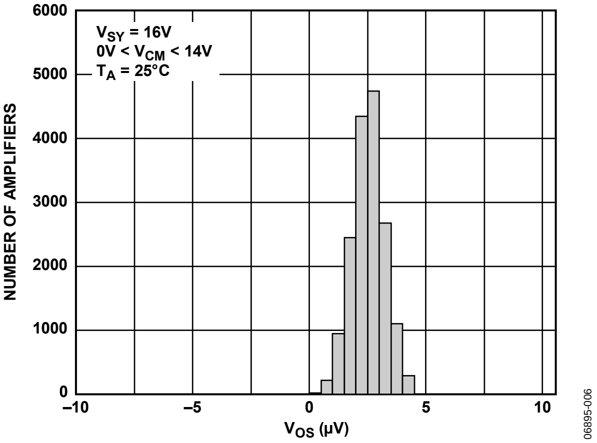

Figure 6. Input Offset Voltage Distribution

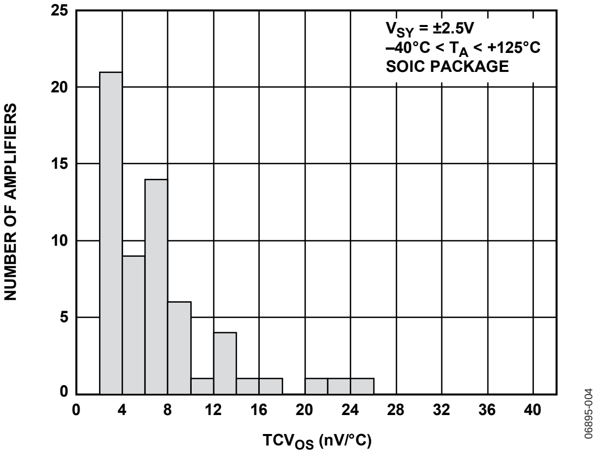

Figure 4. Input Offset Voltage Drift Distribution

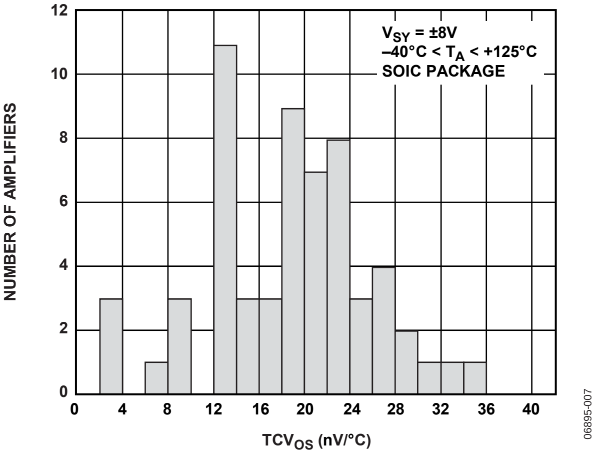

Figure 7. Input Offset Voltage Drift Distribution

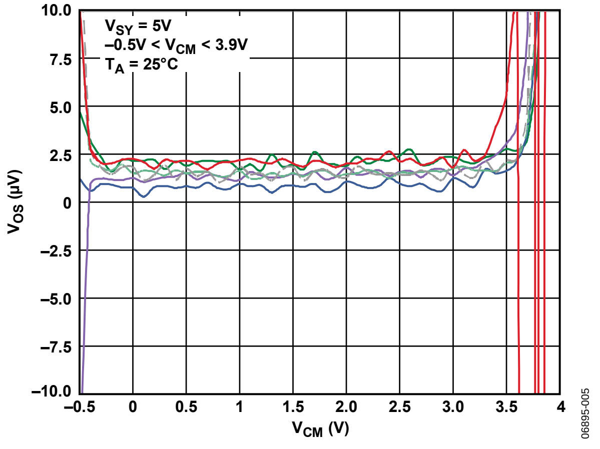

Figure 5. Input Offset Voltage vs. Common-Mode Voltage

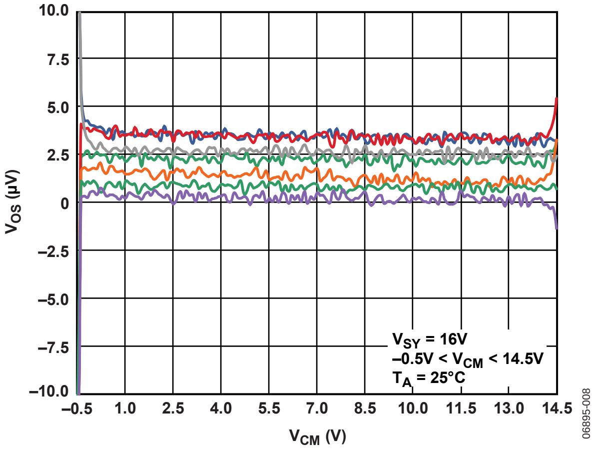

Figure 8. Input Offset Voltage vs. Common-Mode Voltage

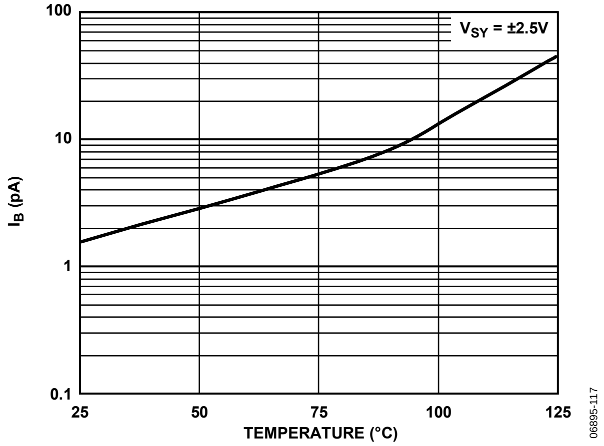

Figure 9. Input Bias Current vs. Temperature

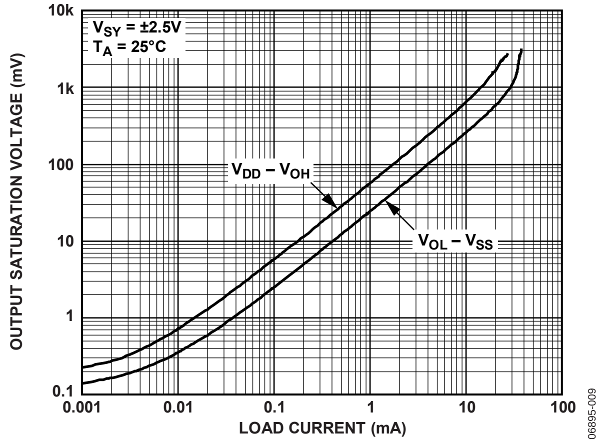

Figure 10. Output Voltage to Supply Rail vs. Load Current

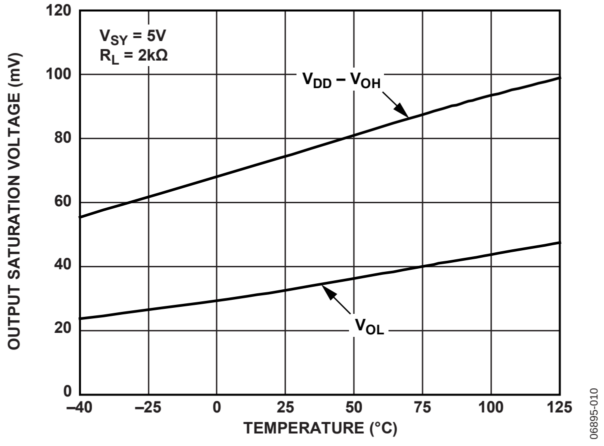

Figure 11. Output Saturation Voltage vs. Temperature

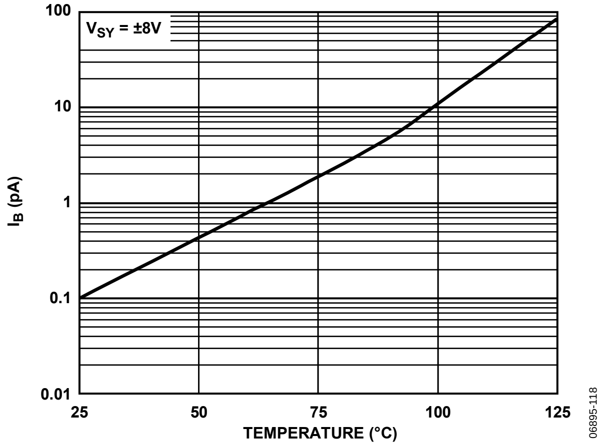

Figure 12. Input Bias Current vs. Temperature

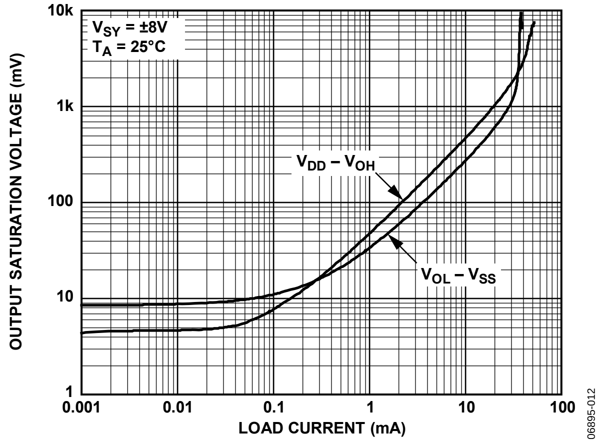

Figure 13. Output Voltage to Supply Rail vs. Load Current

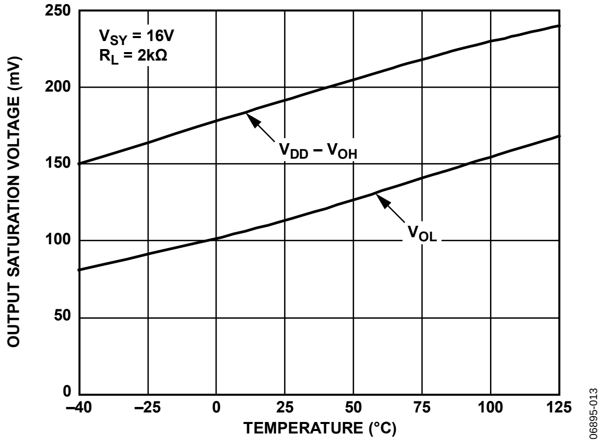

Figure 14. Output Saturation Voltage vs. Temperature

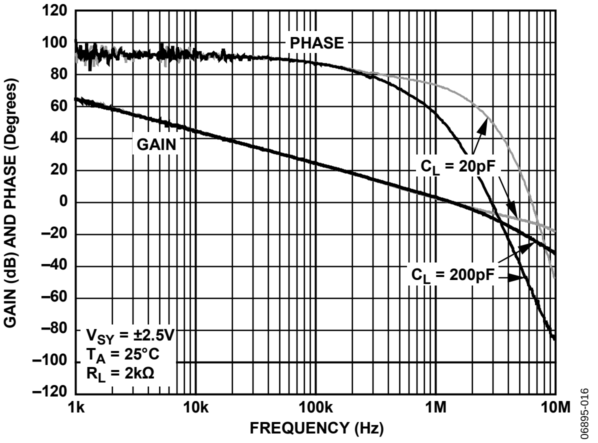

Figure 15. Open-Loop Gain and Phase vs. Frequency

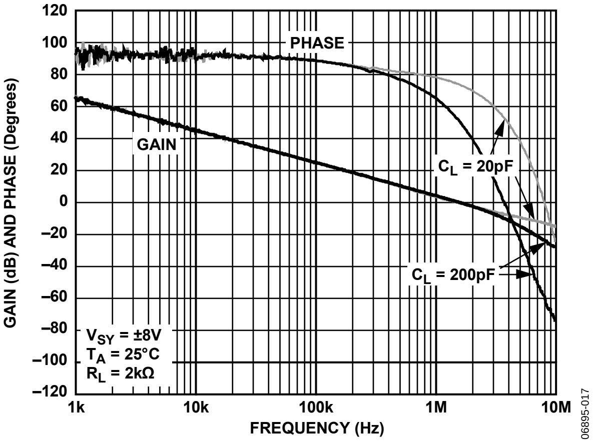

Figure 18. Open-Loop Gain and Phase vs. Frequency

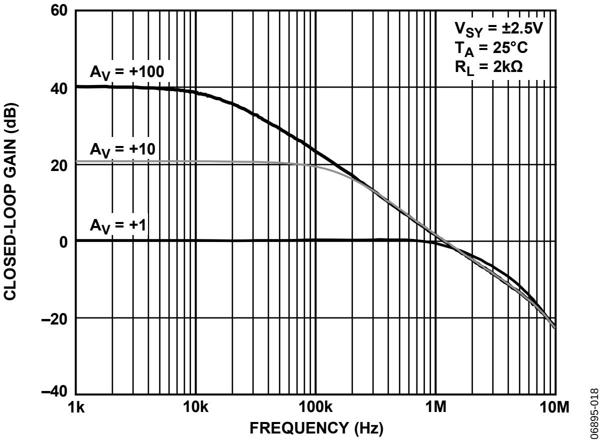

Figure 16. Closed-Loop Gain vs. Frequency

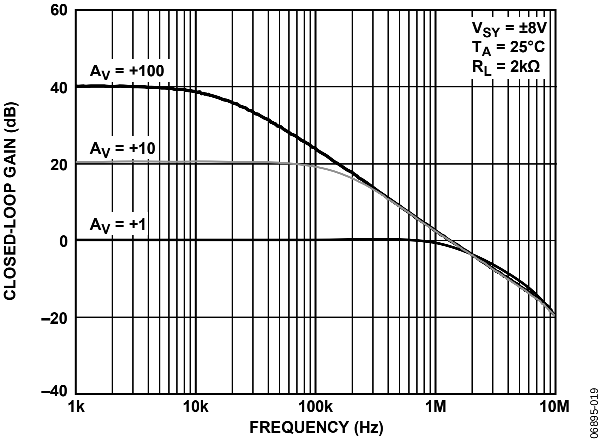

Figure 19. Closed-Loop Gain vs. Frequency

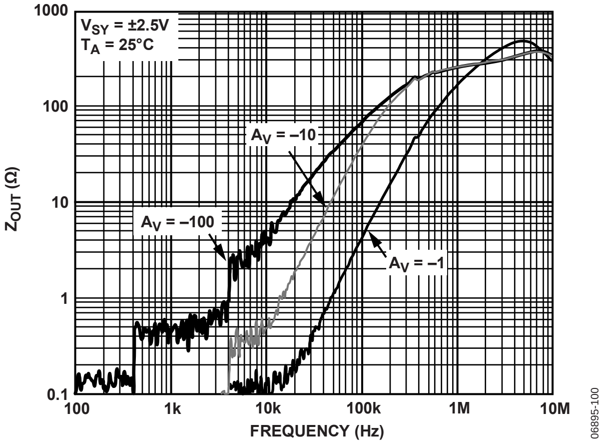

Figure 17. Output Impedance vs. Frequency

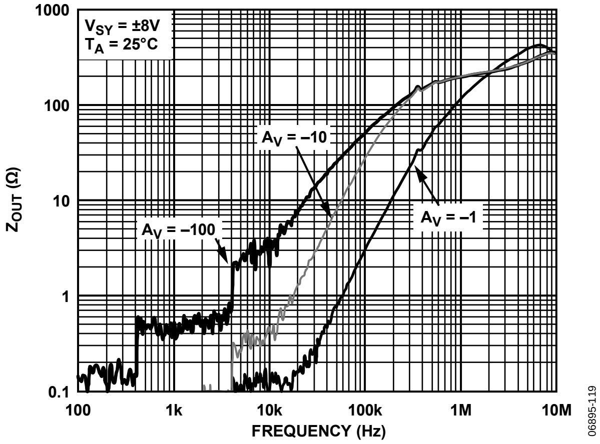

Figure 20. Output Impedance vs. Frequency

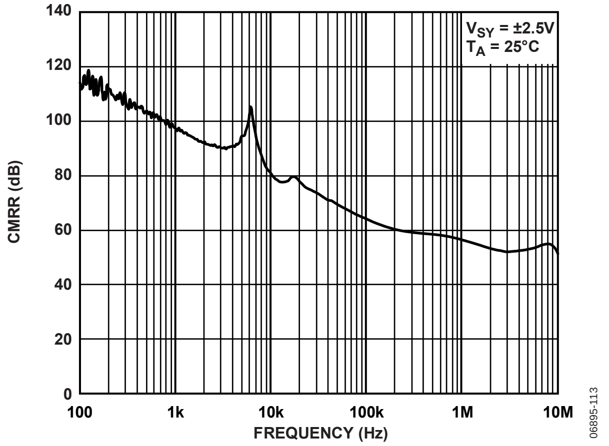

Figure 21. CMRR vs. Frequency

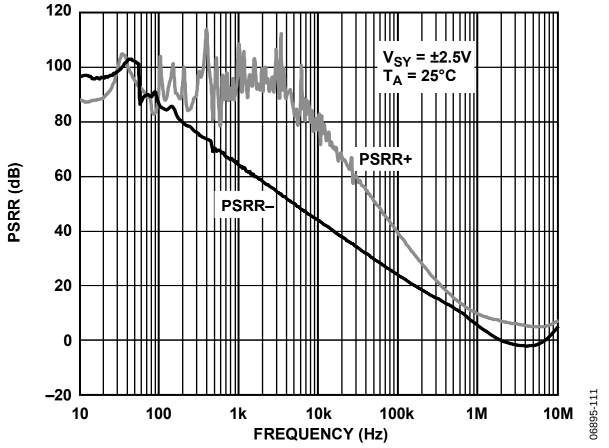

Figure 22. PSRR vs. Frequency

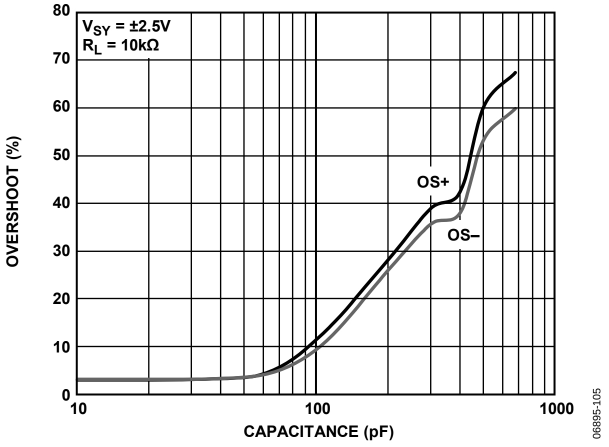

Figure 23. Small Signal Overshoot vs. Load Capacitance

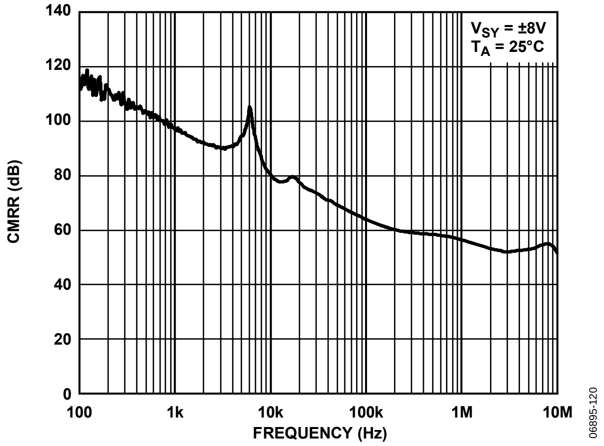

Figure 24. CMRR vs. Frequency

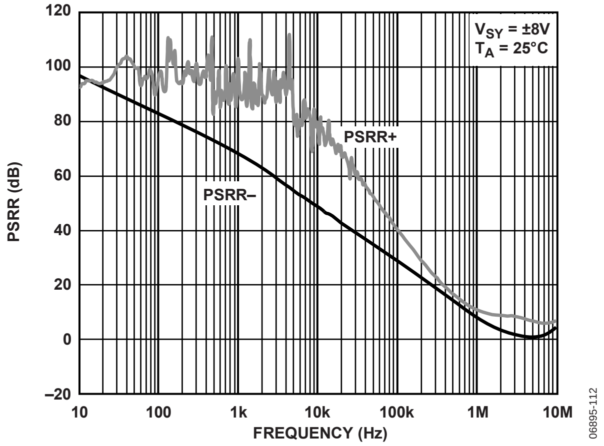

Figure 25. PSRR vs. Frequency

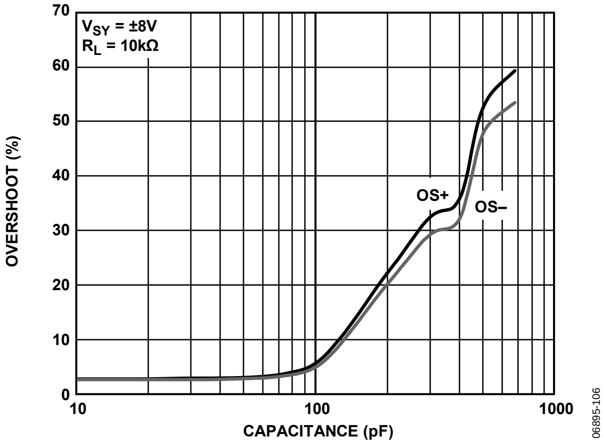

Figure 26. Small Signal Overshoot vs. Load Capacitance

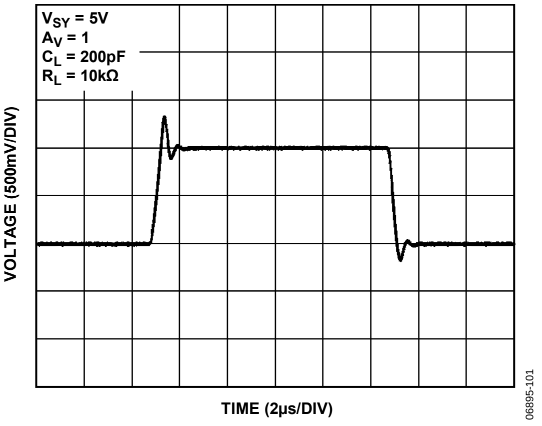

Figure 27. Large Signal Transient Response

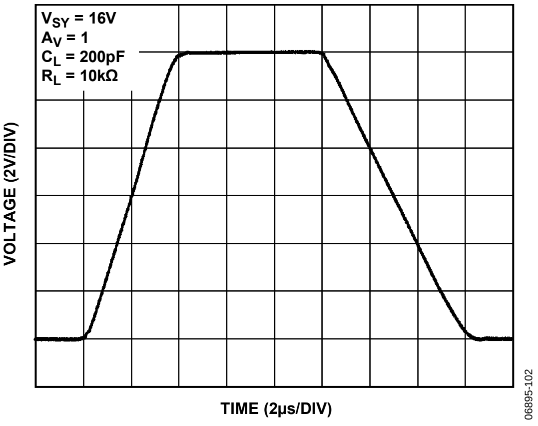

Figure 30. Large Signal Transient Response

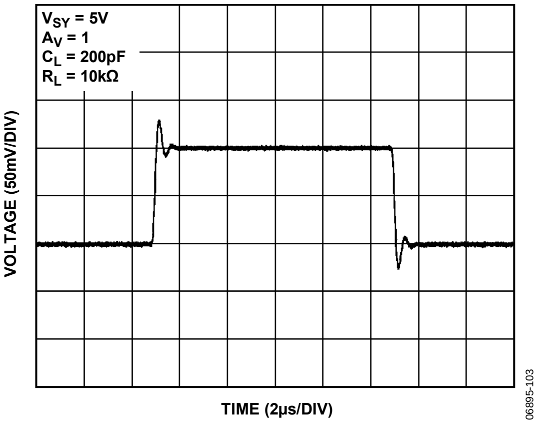

Figure 28. Small Signal Transient Response

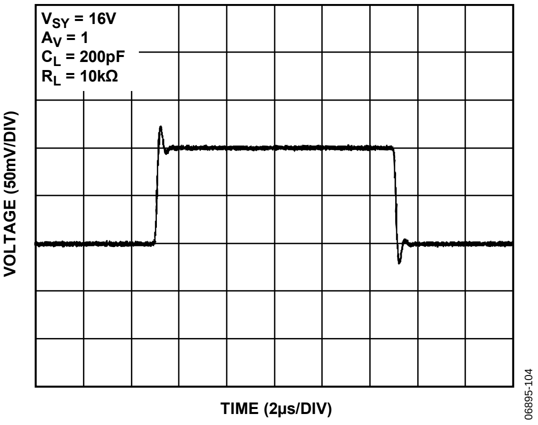

Figure 31. Small Signal Transient Response

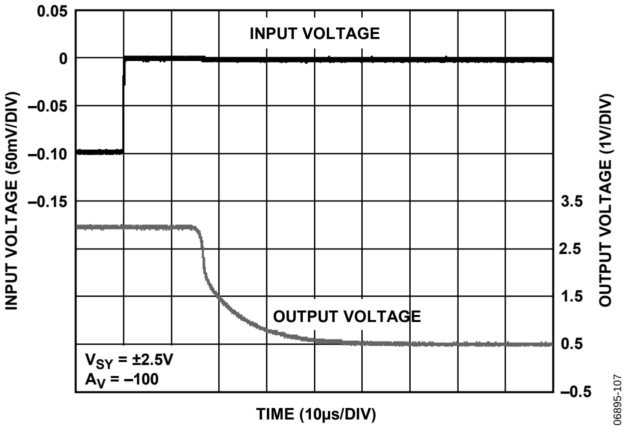

Figure 29. Negative Overload Recovery

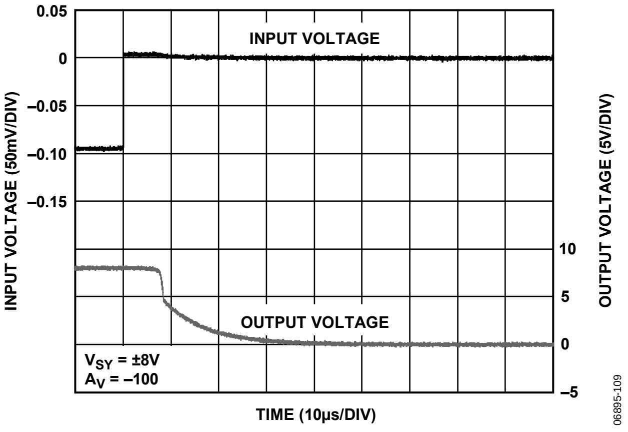

Figure 32. Negative Overload Recovery

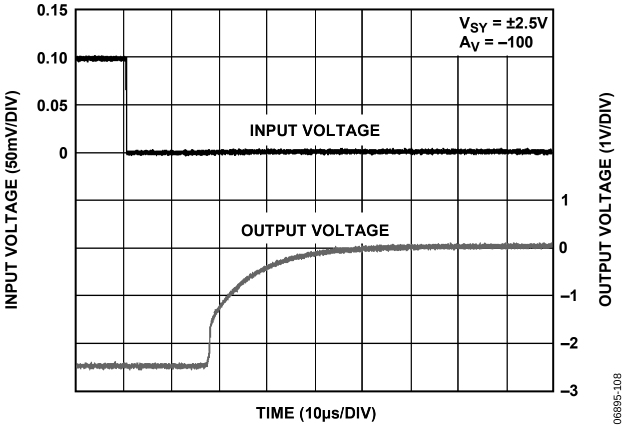

Figure 33. Positive Overload Recovery

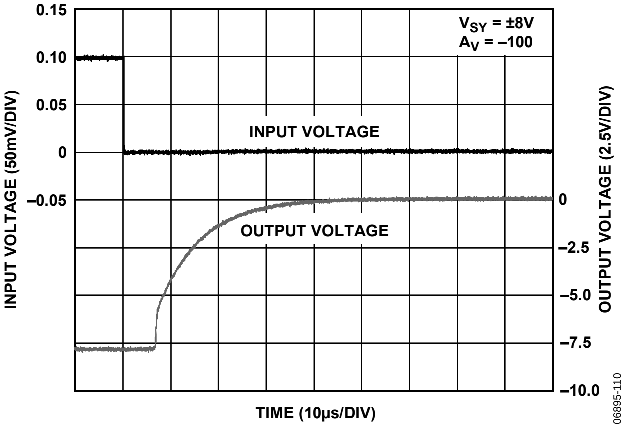

Figure 36. Positive Overload Recovery

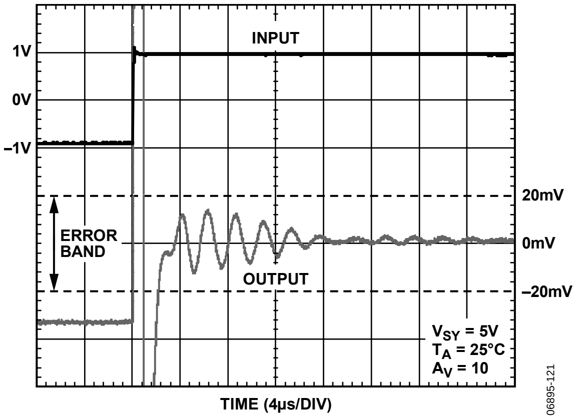

Figure 34. Positive Settling Time to 0.1% 5 V

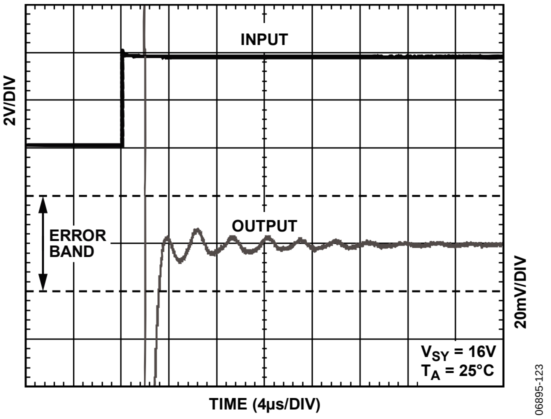

Figure 37. Positive Settling Time to 0.1% 16 V

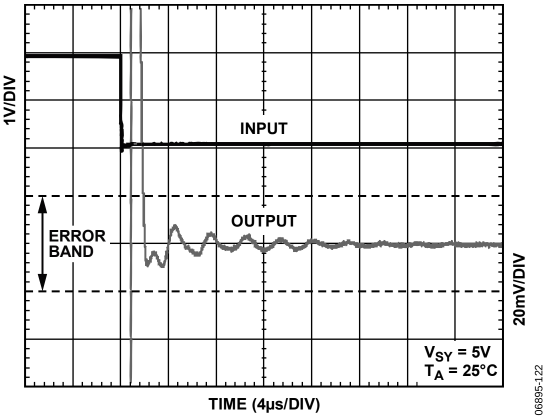

Figure 35. Negative Settling Time to 0.1% 5 V

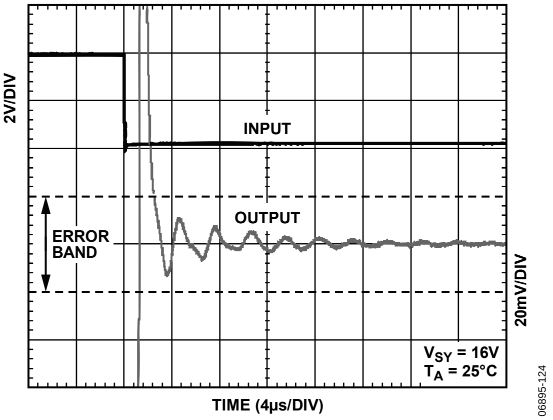

Figure 38. Negative Settling Time to 0.1% 16 V

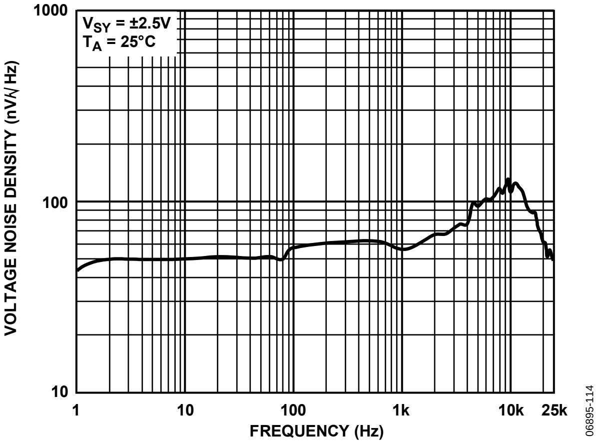

Figure 39. Voltage Noise Density

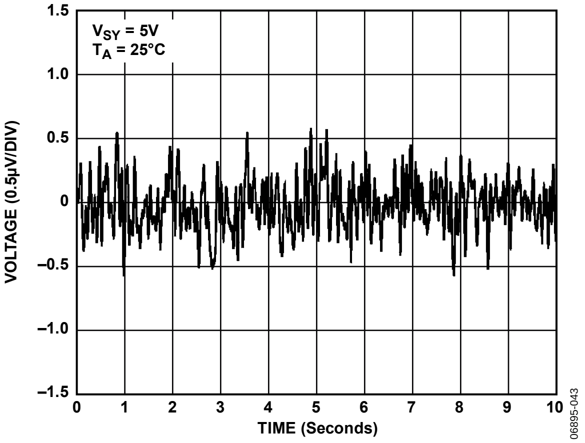

Figure 40. 0.1 Hz to 10 Hz Noise

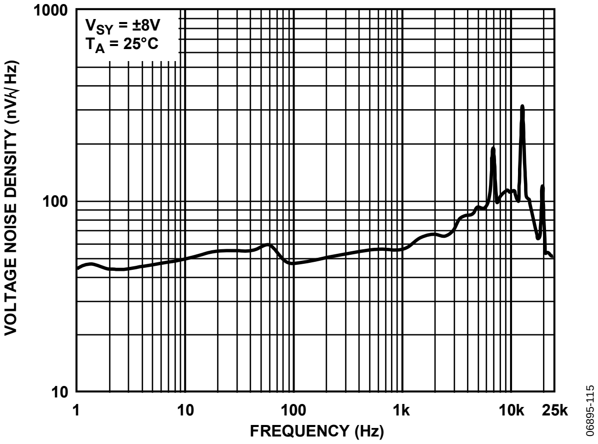

Figure 41. Voltage Noise Density

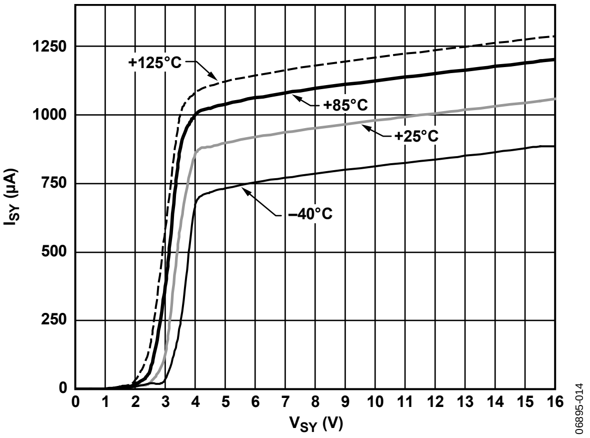

Figure 42. Supply Current vs. Supply Voltage

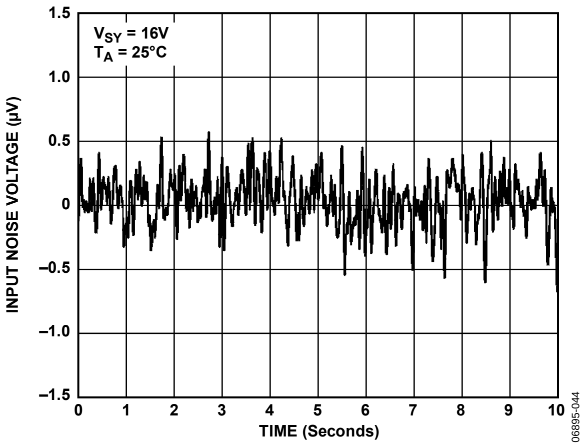

Figure 43. 0.1 Hz to 10 Hz Noise

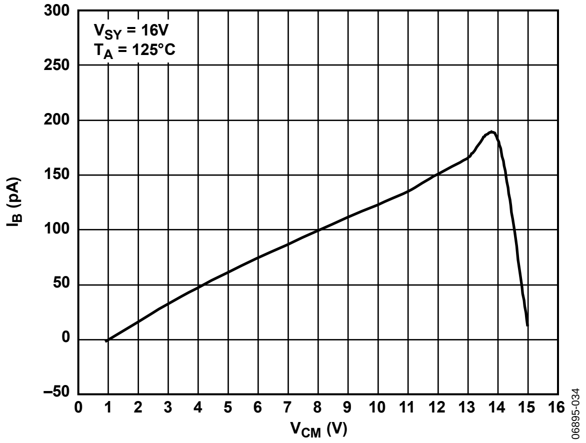

Figure 44. Input Bias Current vs. Input Common-Mode Voltage

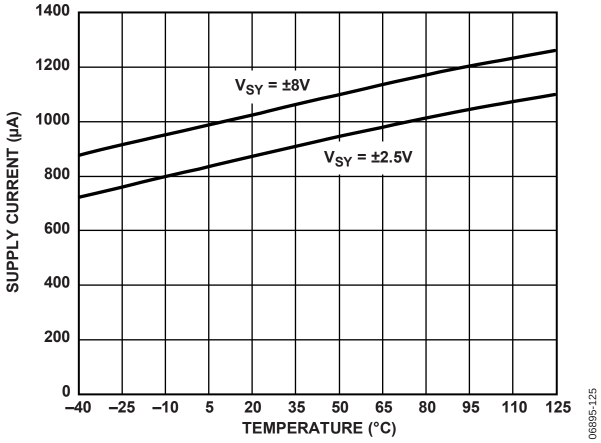

Figure 45. Supply Current vs. Temperature

THEORY OF OPERATION

The AD8638 is a single-supply, ultrahigh precision, rail-to-rail output operational amplifier. The typical offset voltage of less than 1 μV allows the amplifier to be easily configured for high gains without risk of excessive output voltage errors. The extremely small temperature drift of 30 nV/°C ensures a minimum offset voltage error over the entire temperature range of −40°C to +125°C, making the amplifier ideal for a variety of sensitive measurement applications in harsh operating environments.

The AD8638 achieves a high degree of precision through a patented auto-zeroing topology. This unique topology allows the AD8638 to maintain low offset voltage over a wide temperature range and over the operating lifetime. The AD8638 also optimizes the noise and bandwidth over previous generations of auto-zero amplifiers, offering the lowest voltage noise of any auto-zero amplifier by more than 50%.

Previous designs used either auto-zeroing or chopping to add precision to the specifications of an amplifier. Auto-zeroing results in low noise energy at the auto-zeroing frequency, at the expense of higher low frequency noise due to aliasing of wideband noise into the auto-zeroed frequency band. Chopping results in lower low frequency noise at the expense of larger noise energy at the chopping frequency. The AD8638 family uses both auto-zeroing and chopping in a patented ping-pong arrangement to obtain lower low frequency noise together with lower energy at the chopping and auto-zeroing frequencies, maximizing the signal-to-noise ratio (SNR) for the majority of applications without the need for additional filtering. The relatively high clock frequency of 15 kHz simplifies filter requirements for a wide, useful, noise-free bandwidth.

The AD8638 is among the few auto-zero amplifiers offered in the 5-lead SOT-23 package. This provides significant improvement over the ac parameters of previous auto-zero amplifiers. The AD8638 has low noise over a relatively wide bandwidth (0 Hz to 10 kHz) and can be used where the highest dc precision is required. In systems with signal bandwidths ranging from 5 kHz to 10 kHz, the AD8638 provides true 16-bit accuracy, making this device the best choice for very high resolution systems.

1/f NOISE

1/f noise, also known as pink noise, is a major contributor to errors in dc-coupled measurements. This 1/f noise error term can be in the range of several μV or more and, when amplified by the closed-loop gain of the circuit, can show up as a large output signal. For example, when an amplifier with 5 μV p-p 1/f noise is configured for a gain of 1000, its output has 5 mV of error due to the 1/f noise. However, the AD8638 eliminates 1/f noise internally and thus significantly reduces output errors.

The internal elimination of 1/f noise is accomplished as follows: 1/f noise appears as a slowly varying offset to AD8638 inputs. Auto-zeroing corrects any dc or low frequency offset. Therefore, the 1/f noise component is essentially removed, leaving the AD8638 free of 1/f noise.

INPUT VOLTAGE RANGE

The AD8638 is not a rail-to-rail input amplifier, therefore, care is required to ensure that both inputs do not exceed the input voltage range. Under normal negative feedback operating conditions, the amplifier corrects its output to ensure that the two inputs are at the same voltage. However, if either input exceeds the input voltage range, the loop opens and large currents begin to flow through the ESD protection diodes in the amplifier.

These diodes are connected between the inputs and each supply rail to protect the input transistors against an electrostatic discharge event, and they are normally reverse-biased. However, if the input voltage exceeds the supply voltage, these ESD diodes can become forward-biased. Without current limiting, excessive amounts of current may flow through these diodes, causing permanent damage to the device. If inputs are subject to overvoltage, insert appropriate series resistors to limit the diode current to less than 5 mA maximum.

OUTPUT PHASE REVERSAL

Output phase reversal occurs in some amplifiers when the input common-mode voltage range is exceeded. As common-mode voltage is moved outside the common-mode range, the outputs of these amplifiers can suddenly jump in the opposite direction to the supply rail. This is the result of the differential input pair shutting down, causing a radical shifting of internal voltages that results in the erratic output behavior.

The AD8638 amplifier has been carefully designed to prevent any output phase reversal if both inputs are maintained within the specified input voltage range. If one or both inputs exceed the input voltage range, but remain within the supply rails, an internal loop opens and the output varies. Therefore, the inputs should always be less than two volts below the positive supply.

OVERLOAD RECOVERY TIME

Many auto-zero amplifiers are plagued by a long overload recovery time, often in ms, due to the complicated settling behavior of the internal nulling loops after saturation of the outputs. The AD8638 is designed so that internal settling occurs within two clock cycles after output saturation happens. This results in a much shorter recovery time, less than 50 μs, when compared to other auto-zero amplifiers. The wide bandwidth of the AD8638 enhances performance when the parts are used to drive loads that inject transients into the outputs. This is a common situation when an amplifier is used to drive the input of switched capacitor ADCs.

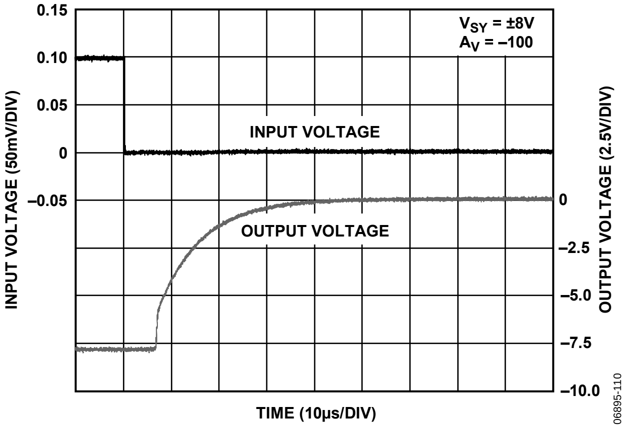

Figure 46. Positive Input Overload Recovery for the AD8638

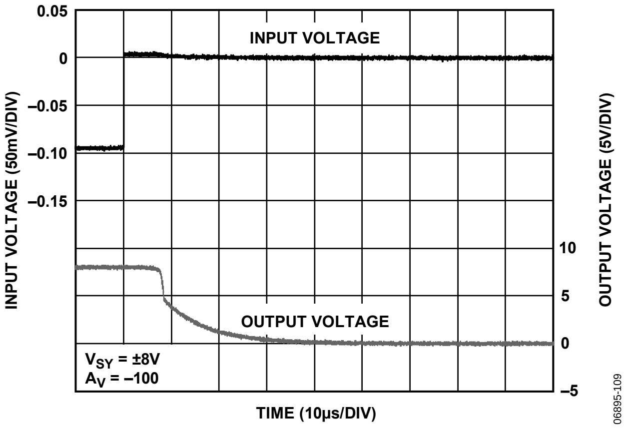

Figure 47. Negative Input Overload Recovery for the AD8638

INFRARED SENSORS

Infrared (IR) sensors, particularly thermopiles, are increasingly used in temperature measurement for applications as wide ranging as automotive climate control, human ear thermometers, home insulation analysis, and automotive repair diagnostics. The relatively small output signal of the sensor demands high gain with very low offset voltage and drift to avoid dc errors.

If interstage ac coupling is used, as shown in Figure 48, low offset and drift prevent the output of the input amplifier from drifting close to saturation. The low input bias currents generate minimal errors from the output impedance of the sensor. Similar to pressure sensors, the very low amplifier drift with time and temperature eliminates additional errors once the system is calibrated at room temperature. The low 1/f noise improves SNR for dc measurements taken over periods often exceeding one-fifth of a second.

Figure 48 shows a circuit that can amplify ac signals from 100 µV to 300 µV up to the 1 V to 3 V levels, with a gain of 10,000 for accurate analog-to-digital conversions.

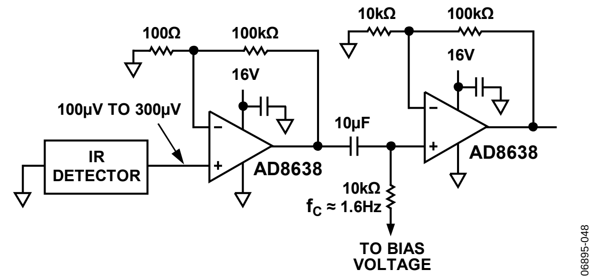

Figure 48. AD8638 Used as a Preamplifier for Thermopile

PRECISION CURRENT SHUNT SENSOR

A precision current shunt sensor benefits from the unique attributes of auto-zero amplifiers when used in a differencing configuration, as shown in Figure 49. Current shunt sensors are used in precision current sources for feedback control systems. They are also used in a variety of other applications, including battery fuel gauging, laser diode power measurement and control, torque feedback controls in electric power steering, and precision power metering.

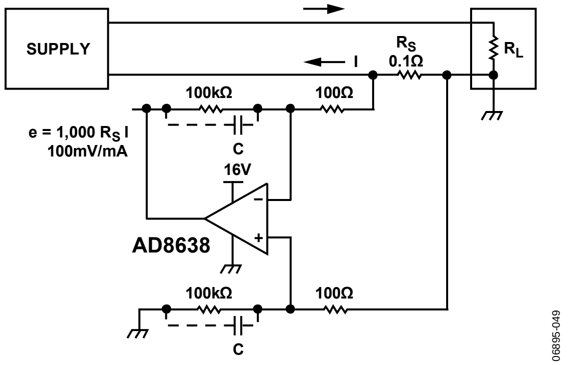

Figure 49. Low-Side Current Sensing

In such applications, it is desirable to use a shunt with very low resistance to minimize the series voltage drop; this minimizes wasted power and allows the measurement of high currents while saving power. A typical shunt might be 0.1 Ω. At measured current values of 1 A, the output signal of the shunt is hundreds of mV, or even V, and amplifier error sources are not critical. However, at low measured current values in the 1 mA range, the 100 µV output voltage of the shunt demands a very low offset voltage and drift to maintain absolute accuracy. Low input bias currents are also needed to prevent injected bias current from becoming a significant percentage of the measured current. High open-loop gain, CMRR, and PSRR help to maintain the overall circuit accuracy. With the extremely high CMRR of the AD8638, the CMRR is limited by the resistor ratio matching. As long as the rate of change of the current is not too fast, an auto-zero amplifier can be used with excellent results.

OUTPUT AMPLIFIER FOR HIGH PRECISION DACS

The AD8638 can be used as an output amplifier for a 16-bit high precision DAC in a unipolar configuration. In this case, the selected op amp needs to have very low offset voltage (the DAC LSB is 38 μV when operating with a 2.5 V reference) to eliminate the need for output offset trims. Input bias current (typically a few tens of picoamperes) must also be very low because it generates an additional offset error when multiplied by the DAC output impedance (approximately 6 kΩ).

Rail-to-rail output provides full-scale output with very little error. Output impedance of the DAC is constant and code-independent, but the high input impedance of the AD8638 minimizes gain errors. The wide bandwidth of the amplifier also serves well in this case. The amplifier, with a settling time of 4 μs, adds another time constant to the system, increasing the settling time of the output. For example, see Figure 50. The settling time of the AD5541 is 1 μs. The combined settling time is approximately 4.1 μs, as can be derived from the following equation:

$$t_S\ (TOTAL) = \sqrt{(t_S\ DAC)^2 + (t_S AD8638)^2}$$

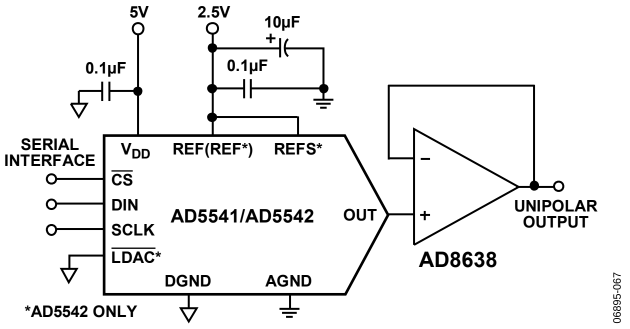

Figure 50. AD8638 Used as an Output Amplifier

OUTLINE DIMENSIONS

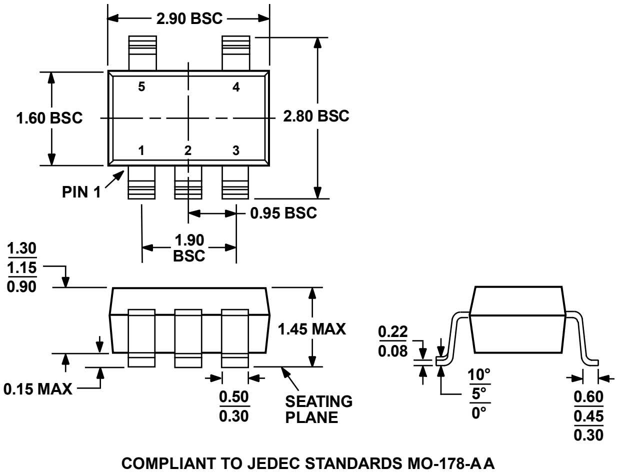

Figure 51. 5-Lead Small Outline Transistor Package [SOT-23]
(RJ-5)
Dimensions shown in millimeters

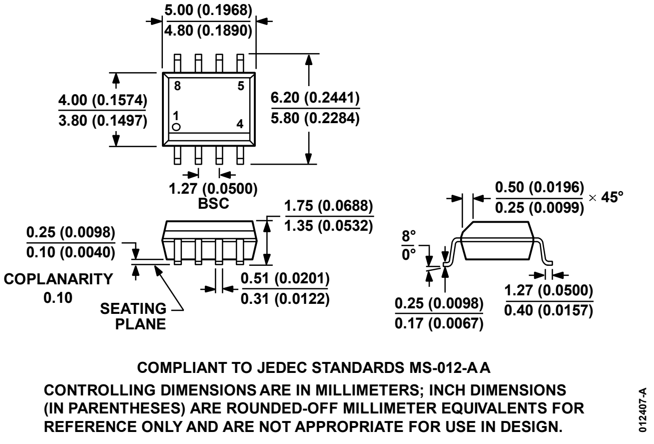

Figure 52. 8-Lead Standard Small Outline Package [SOIC_N]
Narrow Body
(R-8)
Dimensions shown in millimeters and (inches)

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option	Branding
AD8638ARJZ-R2[1]	−40°C to +125°C	5-Lead SOT-23	RJ-5	A1T
AD8638ARJZ-REEL[1]	−40°C to +125°C	5-Lead SOT-23	RJ-5	A1T
AD8638ARJZ-REEL7[1]	−40°C to +125°C	5-Lead SOT-23	RJ-5	A1T
AD8638ARZ[1]	−40°C to +125°C	8-Lead SOIC_N	R-8	
AD8638ARZ-REEL[1]	−40°C to +125°C	8-Lead SOIC_N	R-8	
AD8638ARZ-REEL7[1]	−40°C to +125°C	8-Lead SOIC_N	R-8	

[1] Z = RoHS Compliant Part.

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