



20 μ A Maximum, Rail-to-Rail I/O, Zero Input Crossover Distortion Amplifiers

AD8506/AD8508

FEATURES

PSRR: 100 dB minimum

CMRR: 105 dB typical

Very low supply current: 20 μ A per amp maximum

1.8 V to 5 V single-supply or ± 0.9 V to ± 2.5 V dual-supply operation

Rail-to-rail input and output

Low noise: 45 nV/ $\sqrt{\text{Hz}}$ @ 1 kHz

2.5 mV offset voltage maximum

Very low input bias current: 1 pA typical

APPLICATIONS

Pressure and position sensors

Remote security

Bio sensors

IR thermometers

Battery-powered consumer equipment

Hazard detectors

GENERAL DESCRIPTION

The AD8506/AD8508 are dual and quad micropower amplifiers featuring rail-to-rail input and output swings while operating from a 1.8 V to 5 V single or from ± 0.9 V to ± 2.5 V dual power supply.

Using a novel circuit technology, these low cost amplifiers offer zero crossover distortion (excellent PSRR and CMRR performance) and very low bias current, while operating with a supply current of less than 20 μ A per amplifier. This amplifier family offers the lowest noise in its power class.

This combination of features makes the AD8506/AD8508 amplifiers ideal choices for battery-powered applications because they minimize errors due to power supply voltage variations over the lifetime of the battery and maintain high CMRR even for a rail-to-rail input op amp.

PIN CONFIGURATIONS



Figure 1. 8-Lead MSOP (RM-8)

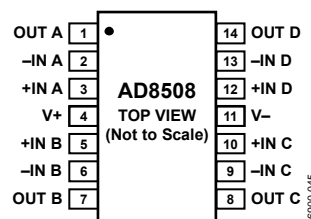


Figure 2. 14-Lead TSSOP (RU-14)

Remote battery-powered sensors, handheld instrumentation and consumer equipment, hazard detection (for example, smoke, fire, and gas), and patient monitors can benefit from the features of the AD8506/AD8508 amplifiers.

The AD8506/AD8508 are specified for both the industrial temperature range of -40°C to $+85^{\circ}\text{C}$ and the extended industrial temperature range of -40°C to $+125^{\circ}\text{C}$. The AD8506 dual amplifiers are available in an 8-lead MSOP package. The AD8508 quad amplifiers are available in the 14-lead TSSOP package.

Rev. A

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One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
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REVISION HISTORY

7/08—Rev. 0 to Rev. A

Added AD8508	Universal
Added TSSOP Package	Universal
Changes to Features Section and General Description Section .	1
Added Figure 2; Renumbered Sequentially	1
Changed Electrical Characteristics Heading to Electrical	
Characteristics—5 V Operation	3
Changes to Table 1.....	3
Added Electrical Characteristics—1.8 V Operation Heading....	4
Changes to Table 2.....	4
Changes to Table 3, Thermal Resistance Section, and Table 4 ...	5
Added $T_A = 25^\circ\text{C}$ Condition to Typical Performance	
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Changes to Figure 3, Figure 4, Figure 6, and Figure 7	6
Added Figure 11 and Figure 14.....	7

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Added Theory of Operation Section, Figure 41, and	
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Added Figure 43 and Figure 44	14
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11/07—Revision 0: Initial Version

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS—5 V OPERATION

$V_{SY} = 5\text{ V}$, $V_{CM} = V_{SY}/2$, $T_A = 25^\circ\text{C}$, $R_L = 100\text{ k}\Omega$ to GND, unless otherwise noted.

Table 1.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
Offset Voltage	V _{OS}	0 V ≤ V _{CM} ≤ 5 V −40°C ≤ T _A ≤ +125°C		0.5	2.5	mV
Input Bias Current	I _B				3.5	mV
		−40°C ≤ T _A ≤ +85°C		1	10	pA
		−40°C ≤ T _A ≤ +125°C			100	pA
Input Offset Current	I _{OS}				600	pA
		−40°C ≤ T _A ≤ +85°C		0.5	5	pA
		−40°C ≤ T _A ≤ +125°C			50	pA
Input Voltage Range	CMRR	−40°C ≤ T _A ≤ +125°C			130	pA
		−40°C ≤ T _A ≤ +125°C	0		5	V
		−40°C ≤ T _A ≤ +125°C	90	105		dB
Common-Mode Rejection Ratio	A _{VO}	−40°C ≤ T _A ≤ +85°C	90			dB
		−40°C ≤ T _A ≤ +125°C	85			dB
		0.05 V ≤ V _{OUT} ≤ 4.95 V	105	120		dB
Large Signal Voltage Gain	ΔV _{OS} /ΔT	−40°C ≤ T _A ≤ +125°C	100			dB
		−40°C ≤ T _A ≤ +125°C		2		μV/°C
		−40°C ≤ T _A ≤ +125°C				
Offset Voltage Drift	C _{DIFF}			3		pF
Input Capacitance Differential Mode	C _{CM}			4.2		pF
Input Capacitance Common Mode						
OUTPUT CHARACTERISTICS						
Output Voltage High	V _{OH}	R _L = 100 kΩ to GND	4.98	4.99		V
		−40°C ≤ T _A ≤ +125°C	4.98			V
		R _L = 10 kΩ to GND	4.9	4.95		V
		−40°C ≤ T _A ≤ +125°C	4.9			V
Output Voltage Low	V _{OL}	R _L = 100 kΩ to V _{SY}		2	5	mV
		−40°C ≤ T _A ≤ +125°C			5	mV
		R _L = 10 kΩ to V _{SY}		10	25	mV
		−40°C ≤ T _A ≤ +125°C			30	mV
Short-Circuit Limit	I _{SC}	V _{OUT} = V _{SY} or GND		±45		mA
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	V _{SY} = 1.8 V to 5 V	100	110		dB
		−40°C ≤ T _A ≤ +85°C	100			dB
		−40°C ≤ T _A ≤ +125°C	95			dB
Supply Current per Amplifier	I _{SY}	V _{OUT} = V _{SY} /2		15	20	μA
		−40°C ≤ T _A ≤ +125°C			25	μA
DYNAMIC PERFORMANCE						
Slew Rate	SR	R _L = 100 kΩ, C _L = 10 pF, G = 1		13		mV/μs
Gain Bandwidth Product	GBP	R _L = 1 MΩ, C _L = 20 pF, G = 1		95		kHz
Phase Margin	Φ _M	R _L = 1 MΩ, C _L = 20 pF, G = 1		60		Degrees
NOISE PERFORMANCE						
Voltage Noise	e _n p-p	f = 0.1 Hz to 10 Hz		2.8		μV p-p
Voltage Noise Density	e _n	f = 1 kHz		45		nV/√Hz
Current Noise Density	i _n	f = 1 kHz		15		fA/√Hz

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ELECTRICAL CHARACTERISTICS—1.8 V OPERATION

$V_{SY} = 1.8 \text{ V}$, $V_{CM} = V_{SY}/2$, $T_A = 25^\circ\text{C}$, $R_L = 100 \text{ k}\Omega$ to GND, unless otherwise noted.

Table 2.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
Offset Voltage	V _{OS}	0 V ≤ V _{CM} ≤ 1.8 V −40°C ≤ T _A ≤ +125°C		0.5	2.5 3.5	mV mV
Input Bias Current	I _B	−40°C ≤ T _A ≤ +85°C −40°C ≤ T _A ≤ +125°C		1	10 100	pA pA
Input Offset Current	I _{OS}	−40°C ≤ T _A ≤ +85°C −40°C ≤ T _A ≤ +125°C		0.5	5 600	pA pA
Input Voltage Range		−40°C ≤ T _A ≤ +125°C	0		1.8	V
Common-Mode Rejection Ratio	CMRR	0 V ≤ V _{CM} ≤ 1.8 V −40°C ≤ T _A ≤ +85°C −40°C ≤ T _A ≤ +125°C	85 85 80	100		dB dB dB
Large Signal Voltage Gain	A _{VO}	0.05 V ≤ V _{OUT} ≤ 1.75 V −40°C ≤ T _A ≤ +125°C	95 95	115		dB dB
Offset Voltage Drift	ΔV _{OS} /ΔT	−40°C ≤ T _A ≤ +125°C		2.5		μV/°C
Input Capacitance Differential Mode	C _{DIFF}			3		pF
Input Capacitance Common Mode	C _{CM}			4.2		pF
OUTPUT CHARACTERISTICS						
Output Voltage High	V _{OH}	R _L = 100 kΩ to GND −40°C ≤ T _A ≤ +125°C	1.78 1.78	1.79		V V
		R _L = 10 kΩ to GND −40°C ≤ T _A ≤ +125°C	1.65 1.65	1.75		V V
Output Voltage Low	V _{OL}	R _L = 100 kΩ to V _{SY} −40°C ≤ T _A ≤ +125°C		2	5	mV mV
		R _L = 10 kΩ to V _{SY} −40°C ≤ T _A ≤ +125°C		12	25	mV mV
Short-Circuit Limit	I _{SC}	V _{OUT} = V _{SY} or GND		±4.5		mA
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	V _{SY} = 1.8 V to 5 V −40°C ≤ T _A ≤ +85°C −40°C ≤ T _A ≤ +125°C	100 100 95	110		dB dB dB
Supply Current per Amplifier	I _{SY}	V _{OUT} = V _{SY} /2 −40°C ≤ T _A ≤ +125°C		16.5	20 25	μA μA
DYNAMIC PERFORMANCE						
Slew Rate	SR	R _L = 100 kΩ, C _L = 10 pF, G = 1		13		mV/μs
Gain Bandwidth Product	GBP	R _L = 1 MΩ, C _L = 20 pF, G = 1		95		kHz
Phase Margin	Φ _M	R _L = 1 MΩ, C _L = 20 pF, G = 1		60		Degrees
NOISE PERFORMANCE						
Voltage Noise	e _n p-p	f = 0.1 Hz to 10 Hz		2.8		μV p-p
Voltage Noise Density	e _n	f = 1 kHz		45		nV/√Hz
Current Noise Density	i _n	f = 1 kHz		15		fA/√Hz

ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Rating
Supply Voltage	5.5 V
Input Voltage	$\pm V_{SY} \pm 0.1$ V
Input Current ¹	± 10 mA
Differential Input Voltage ²	$\pm V_{SY}$
Output Short-Circuit Duration to GND	Indefinite
Storage Temperature Range	–65°C to +150°C
Operating Temperature Range	–40°C to +125°C
Junction Temperature Range	–65°C to +150°C
Lead Temperature (Soldering, 60 sec)	300°C

¹ Input pins have clamp diodes to the supply pins. Input current should be limited to 10 mA or less whenever the input signal exceeds the power supply rail by 0.5 V.

² Differential input voltage is limited to 5 V or the supply voltage, whichever is less.

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 two-layer board.

Table 4. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
8-Lead MSOP (RM-8)	190	44	°C/W
14-Lead TSSOP (RU-14)	180	35	°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

$T_A = 25^\circ\text{C}$, unless otherwise noted.

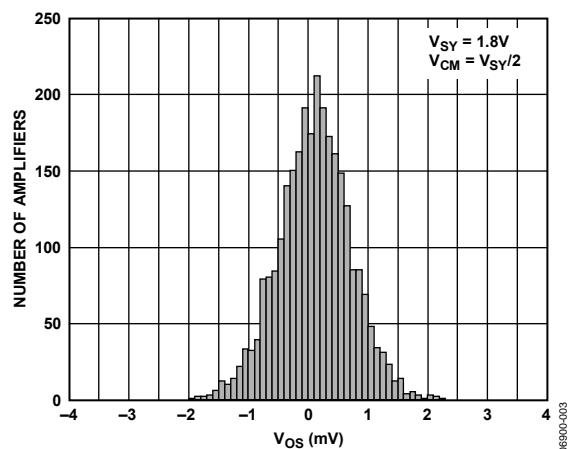


Figure 3. Input Offset Voltage Distribution

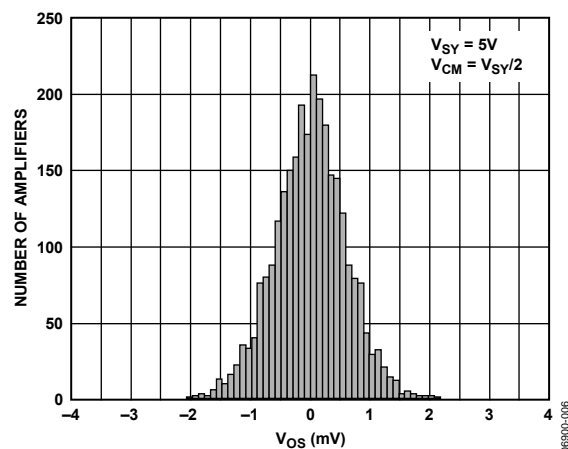


Figure 6. Input Offset Voltage Distribution

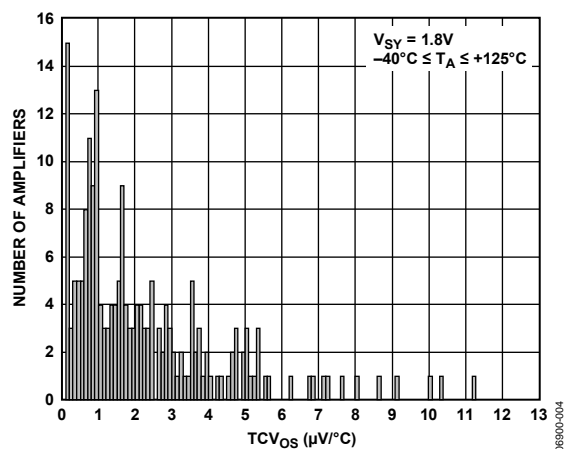


Figure 4. Input Offset Voltage Drift Distribution

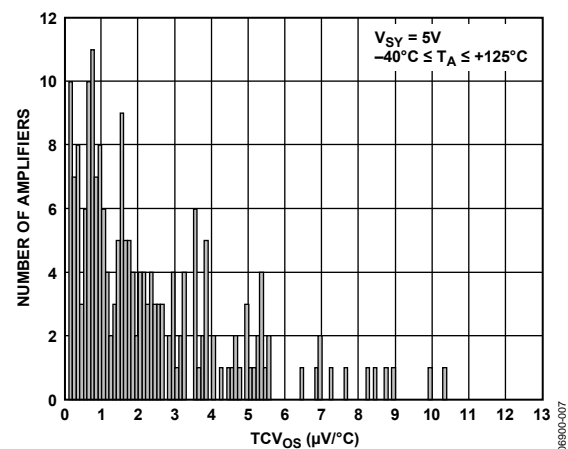


Figure 7. Input Offset Voltage Drift Distribution

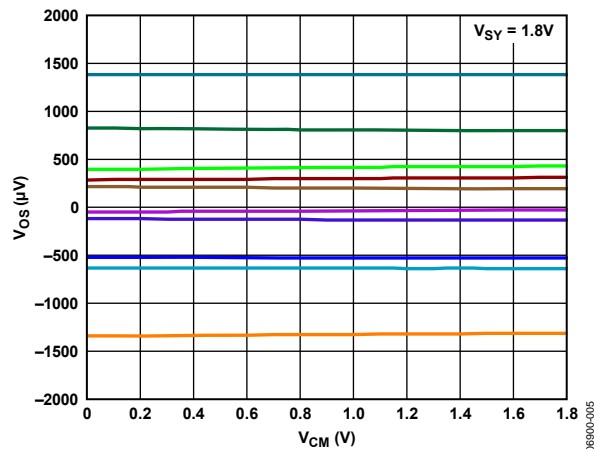


Figure 5. Input Offset Voltage vs. Input Common-Mode Voltage

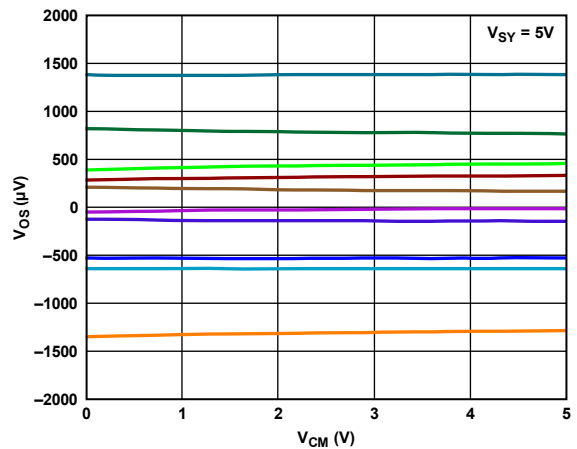


Figure 8. Input Offset Voltage vs. Input Common-Mode Voltage

$T_A = 25^\circ\text{C}$, unless otherwise noted.

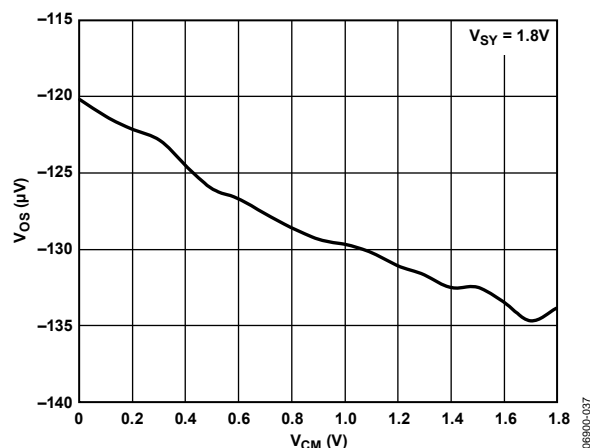


Figure 9. Input Offset Voltage vs. Input Common-Mode Voltage

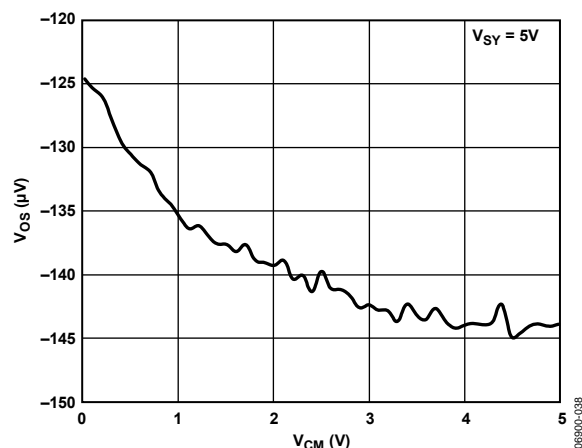


Figure 12. Input Offset Voltage vs. Input Common-Mode Voltage

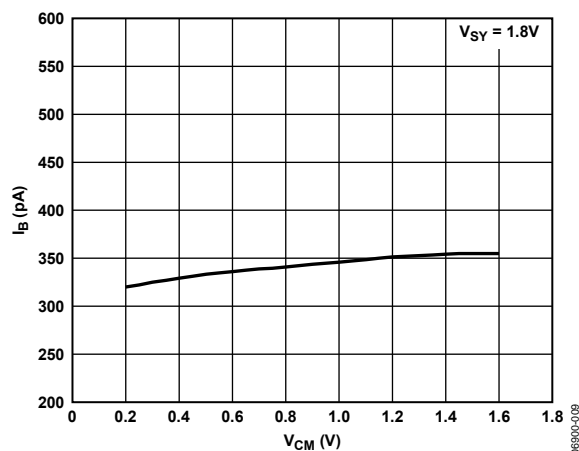


Figure 10. Input Bias Current vs. Common-Mode Voltage at 125°C

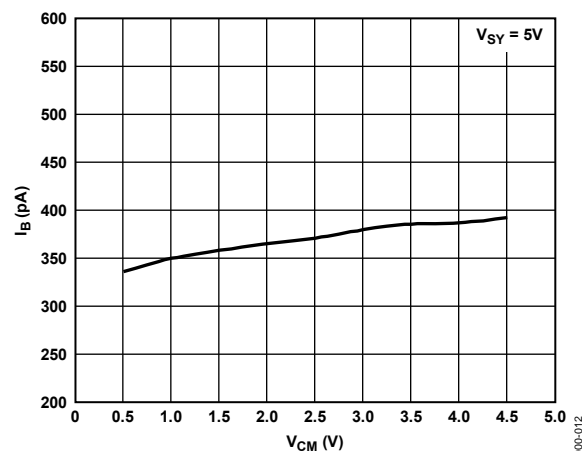


Figure 13. Input Bias Current vs. Common-Mode Voltage at 125°C

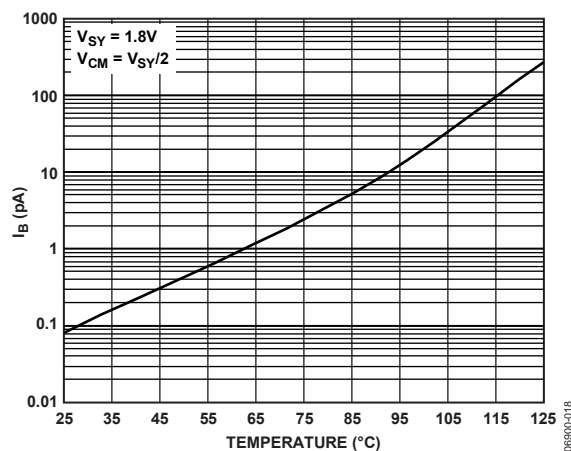


Figure 11. Input Bias Current vs. Temperature

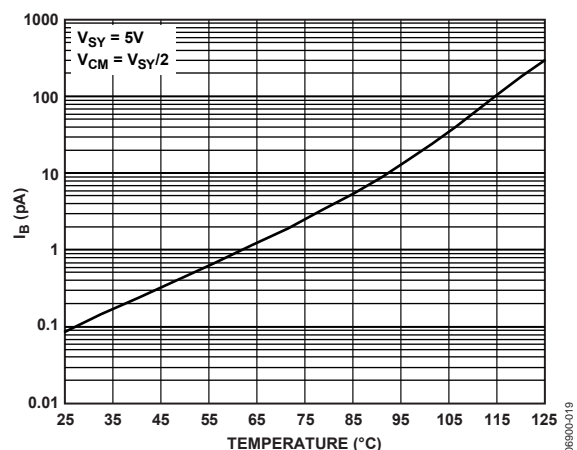


Figure 14. Input Bias Current vs. Temperature

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$T_A = 25^\circ\text{C}$, unless otherwise noted.

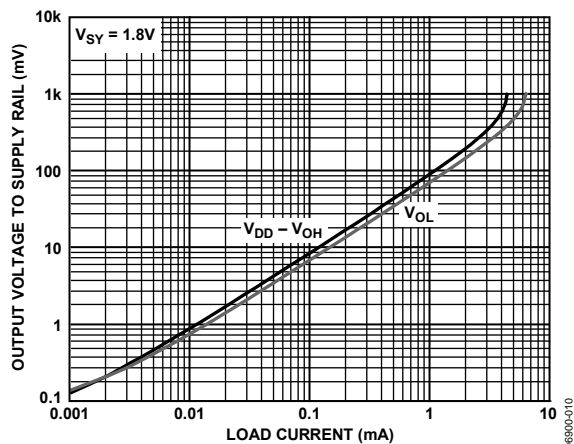


Figure 15. Output Voltage to Supply Rail vs. Load Current

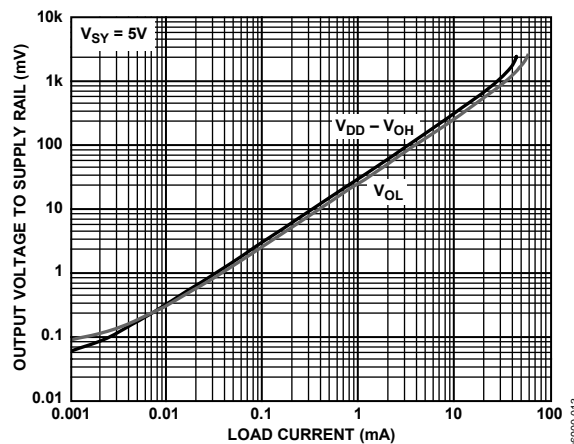


Figure 18. Output Voltage to Supply Rail vs. Load Current

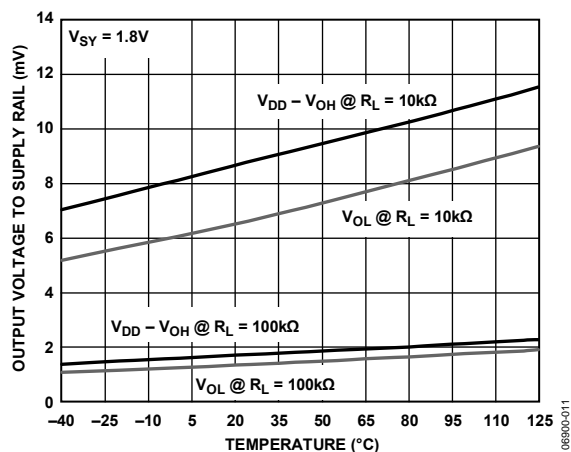


Figure 16. Output Voltage to Supply Rail vs. Temperature

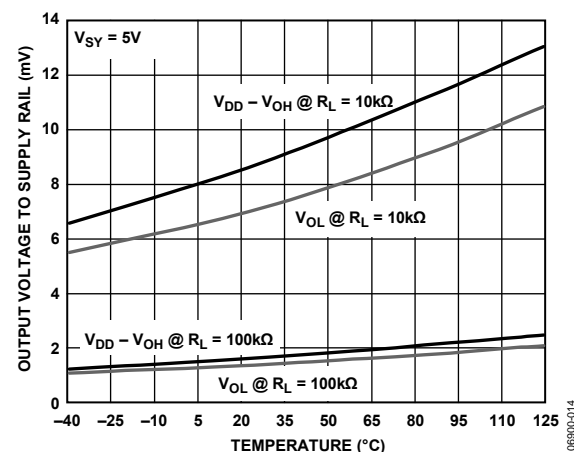


Figure 19. Output Voltage to Supply Rail vs. Temperature

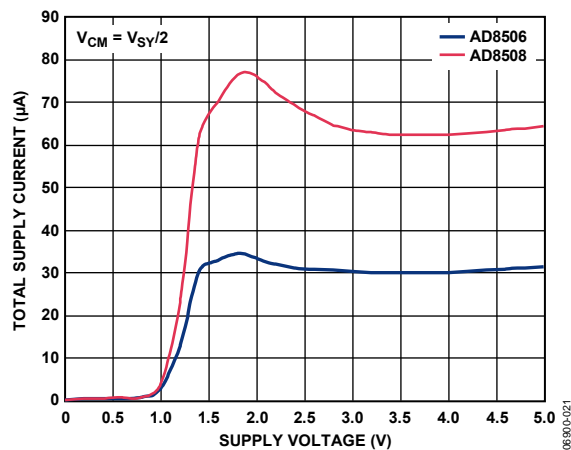


Figure 17. Total Supply Current vs. Supply Voltage

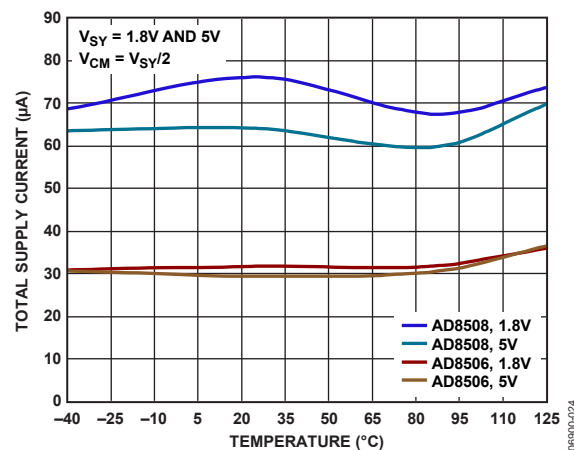


Figure 20. Total Supply Current vs. Temperature

$T_A = 25^\circ\text{C}$, unless otherwise noted.

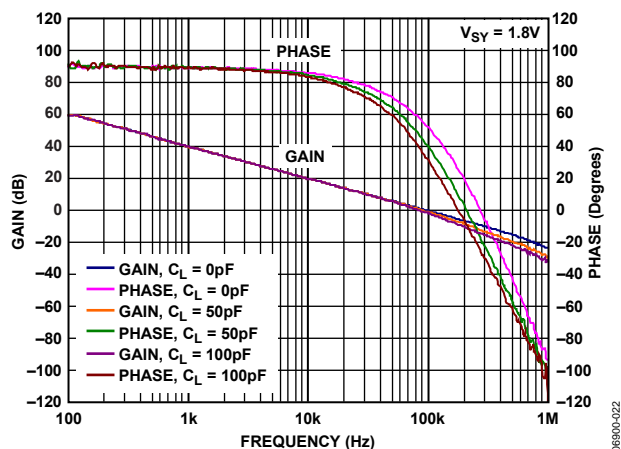


Figure 21. Open-Loop Gain and Phase vs. Frequency

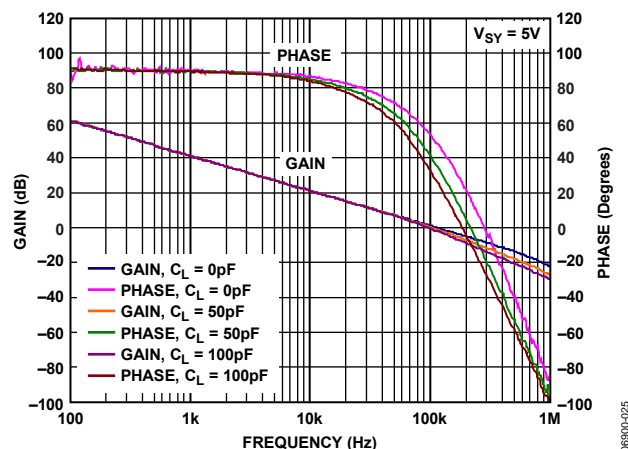


Figure 24. Open-Loop Gain and Phase vs. Frequency

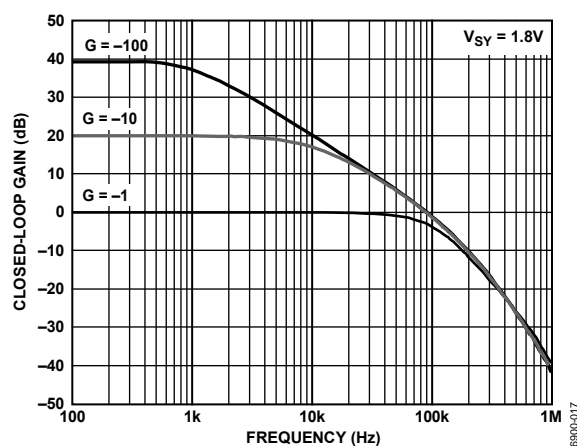


Figure 22. Closed-Loop Gain vs. Frequency

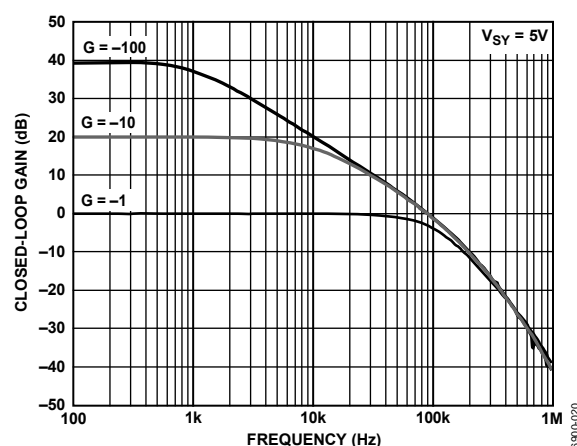


Figure 25. Closed-Loop Gain vs. Frequency

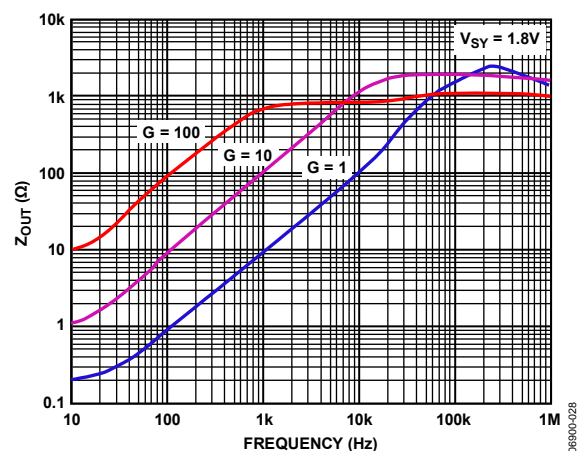


Figure 23. Z_{OUT} vs. Frequency

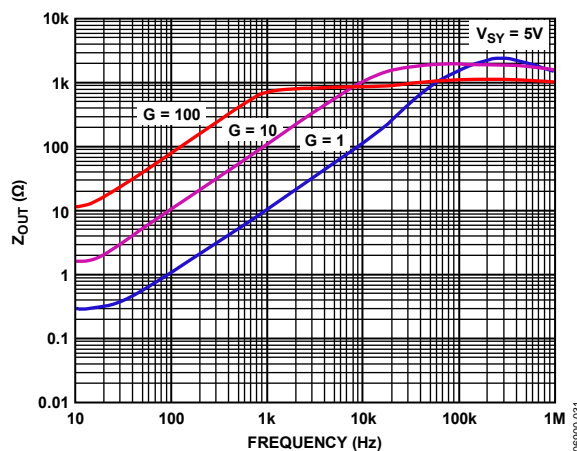


Figure 26. Z_{OUT} vs. Frequency

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$T_A = 25^\circ\text{C}$, unless otherwise noted.

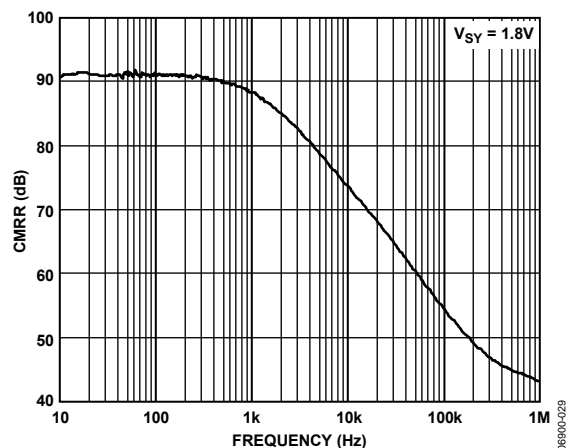


Figure 27. CMRR vs. Frequency

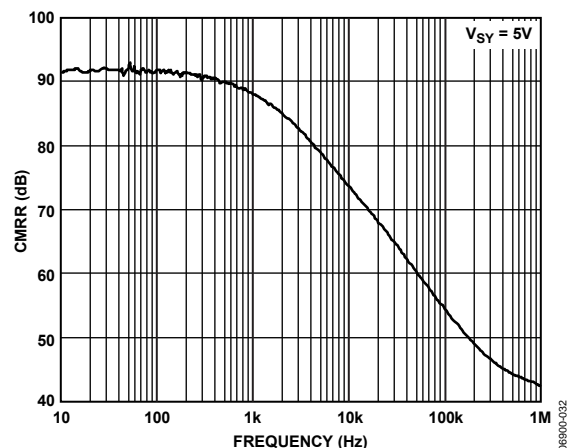


Figure 30. CMRR vs. Frequency

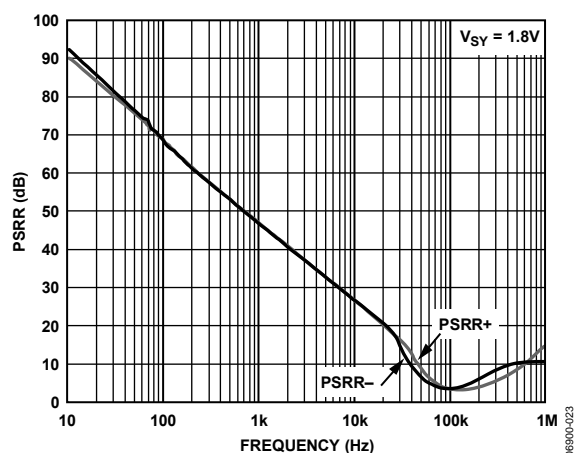


Figure 28. PSRR vs. Frequency

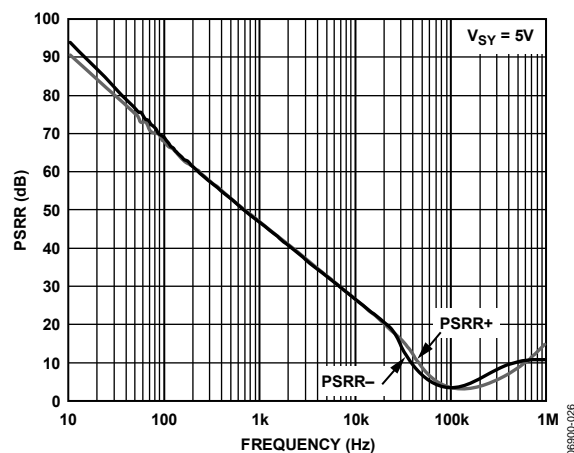


Figure 31. PSRR vs. Frequency

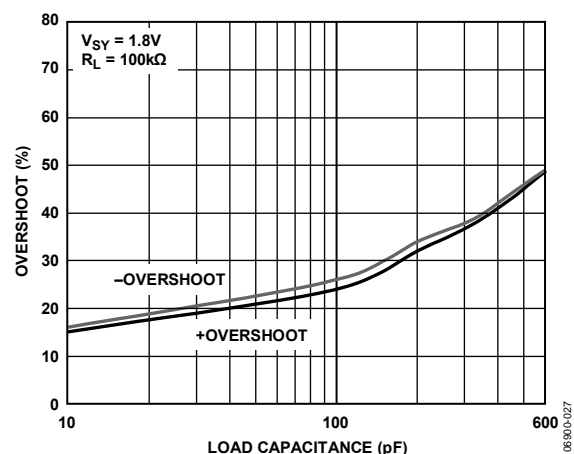


Figure 29. Small Signal Overshoot vs. Load Capacitance

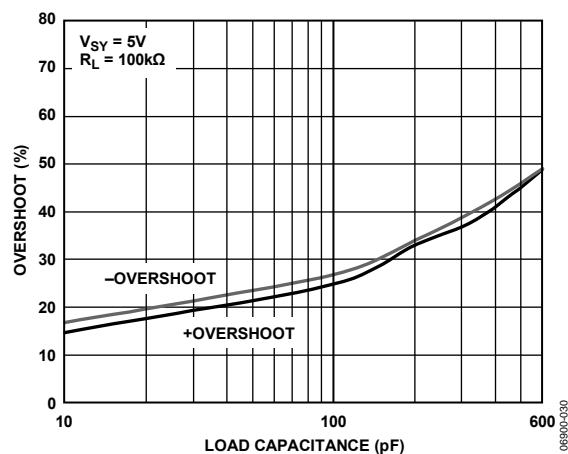


Figure 32. Small Signal Overshoot vs. Load Capacitance

$T_A = 25^\circ\text{C}$, unless otherwise noted.

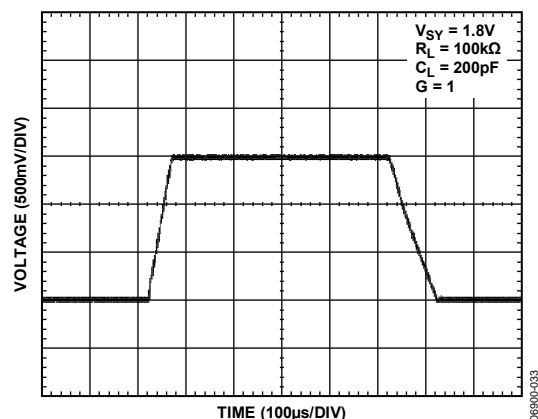


Figure 33. Large Signal Transient Response

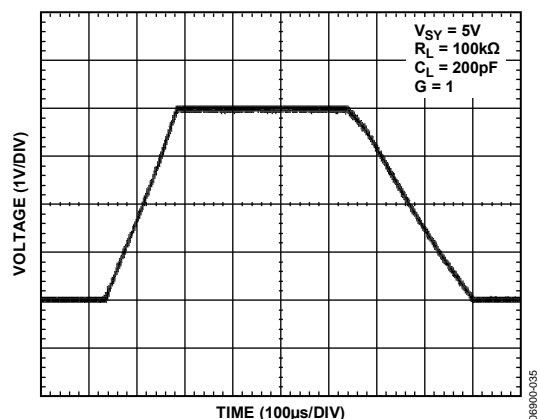


Figure 36. Large Signal Transient Response

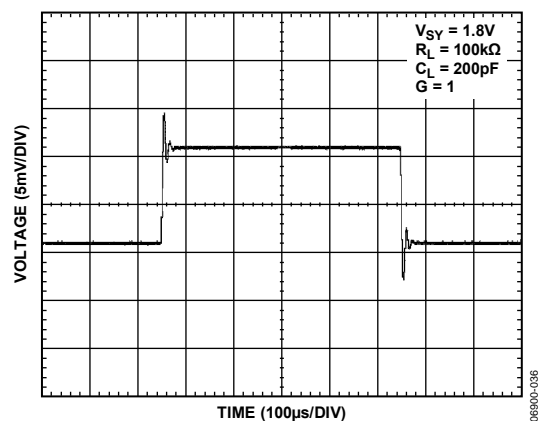


Figure 34. Small Signal Transient Response

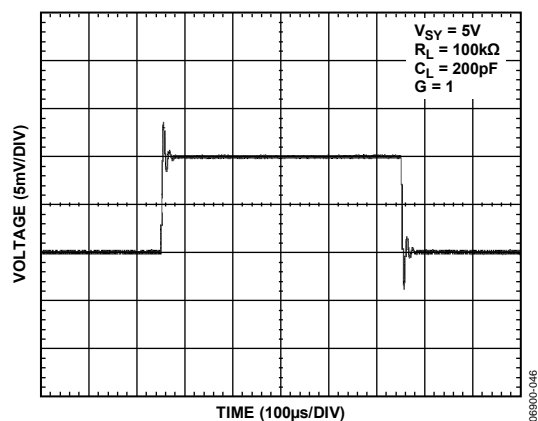


Figure 37. Small Signal Transient Response

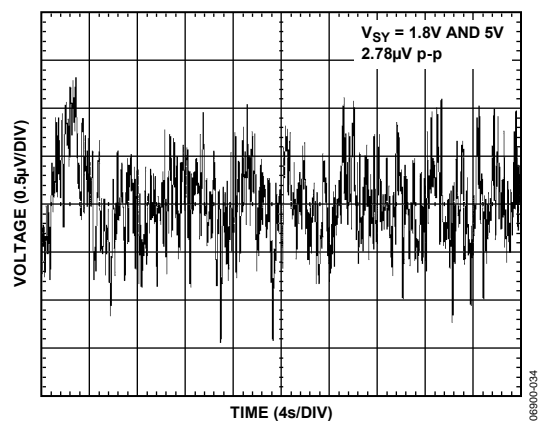


Figure 35. Voltage Noise 0.1 Hz to 10 Hz

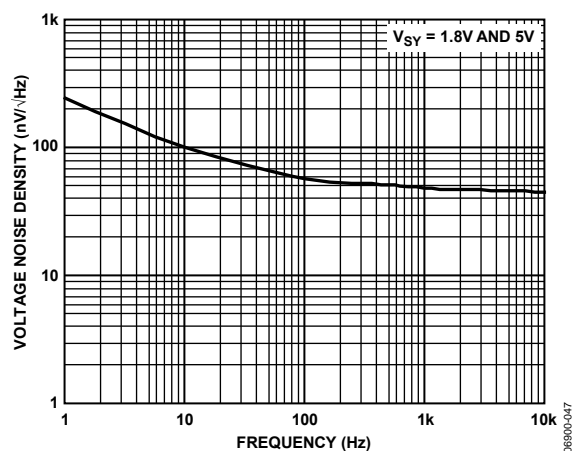


Figure 38. Voltage Noise Density vs. Frequency

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T_A = 25°C, unless otherwise noted.

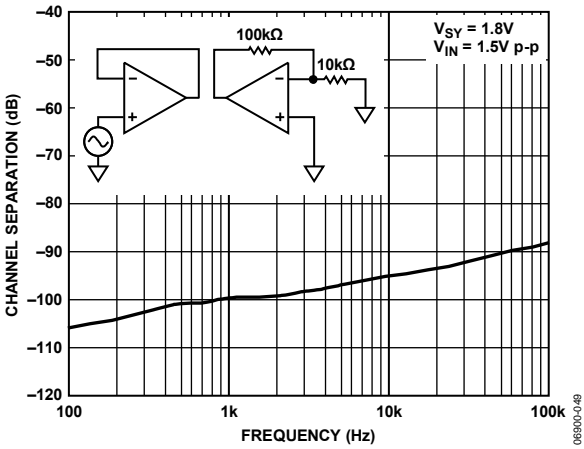


Figure 39. Channel Separation vs. Frequency

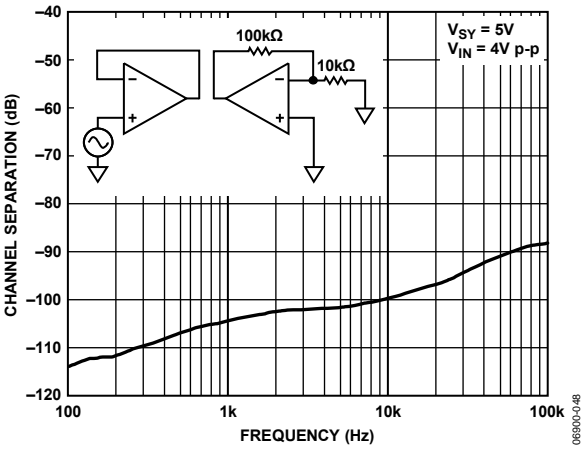


Figure 40. Channel Separation vs. Frequency

The charge pump has been carefully designed so that switching noise components at any frequency, both within and beyond the amplifier bandwidth, are much lower than the thermal noise floor. Therefore, the spurious-free dynamic range (SFDR) is limited only by the input signal and the thermal or flicker noise. There is no intermodulation between input signal and switching noise.

Figure 43 displays a typical front-end section of an operational amplifier with an on-chip charge pump.

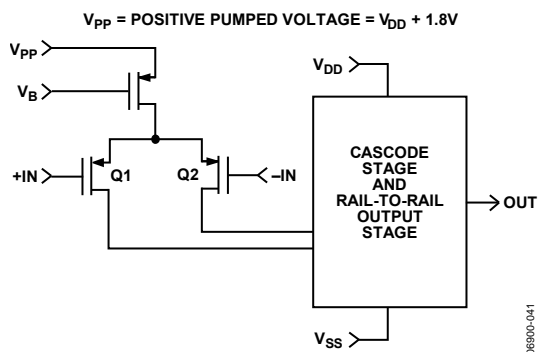


Figure 43. Typical Front-End Section of an Op Amp with Embedded Charge Pump

Figure 44, input offset voltage vs. input common-mode voltage response, shows the typical response of 12 devices from Figure 8. Figure 44 has been expanded so that it is easier to compare with Figure 42, typical input offset voltage vs. common-mode voltage response in a dual differential pair input stage op amp.

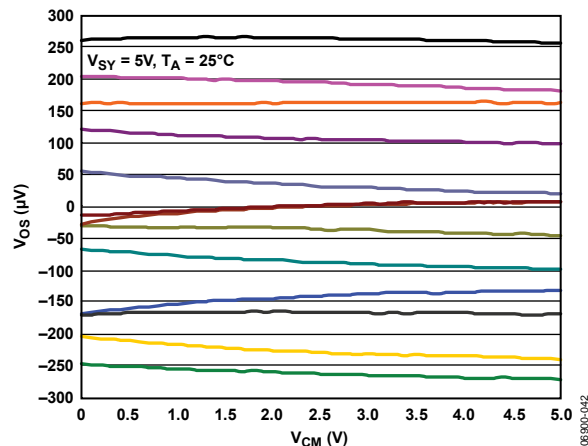


Figure 44. Input Offset Voltage vs. Input Common-Mode Voltage Response (Powered by a 5 V Supply; Results of 12 Units Are Displayed)

This solution improves the CMRR performance tremendously. For instance, if the input varies from rail-to-rail on a 2.5 V supply rail, using a part with a CMRR of 70 dB minimum, an input-referred error of 790 μ V is introduced. Another part with a CMRR of 52 dB minimum generates a 6.3 mV error. The AD8506/AD8508 CMRR of 90 dB minimum causes only a 79 μ V error. As with the PSRR error, there are complex ways to minimize this error, but the AD8506/AD8508 solve this problem without incurring unnecessary circuitry complexity or increased cost.

APPLICATIONS INFORMATION

PULSE OXIMETER CURRENT SOURCE

A pulse oximeter is a noninvasive medical device used for measuring continuously the percentage of hemoglobin (Hb) saturated with oxygen and the pulse rate of a patient. Hemoglobin that is carrying oxygen (oxyhemoglobin) absorbs light in the infrared (IR) region of the spectrum; hemoglobin that is not carrying oxygen (deoxyhemoglobin) absorbs visible red (R) light. In pulse oximetry, a clip containing two LEDs (sometimes more, depending on the complexity of the measurement algorithm) and the light sensor (photodiode) is placed on the finger or earlobe of the patient. One LED emits red light (600 nm to 700 nm) and the other emits light in the near IR (800 nm to 900 nm) region. The clip is connected by a cable to a processor unit. The LEDs are rapidly and sequentially excited by two current sources (one for each LED), whose dc levels depend on the LED being driven, based on manufacturer requirements, and the detector is synchronized to capture the light from each LED as it is transmitted through the tissue.

An example design of a dc current source driving the red and infrared LEDs is shown in Figure 45. These dc current sources allow 62.5 mA and 101 mA to flow through the red and infrared LEDs, respectively. First, to prolong battery life, the LEDs are driven only when needed. One-third of the ADG733 SPDT analog switch is used to disconnect/connect the 1.25 V voltage reference from/to each current circuit. When driving the LEDs, the ADR1581 1.25 V voltage reference is buffered by $\frac{1}{2}$ of the AD8506; the presence of this voltage on the noninverting input forces the output of the op amp (due to the negative feedback) to maintain a level that makes its inverting input-to-track the noninverting pin. Therefore, the 1.25 V appears in parallel with the 20 Ω R1 or 12.4 Ω R5 current source resistor, creating the flow of the 62.5 mA or 101 mA current through the red or infrared LED as the output of the op amp turns on the Q1 or Q2 N-MOSFET IRLMS2002.

The maximum total quiescent currents for the $\frac{1}{2}$ AD8506, ADR1581, and ADG733 are 25 μ A, 70 μ A, and 1 μ A, respectively, making a total of 96 μ A current consumption (480 μ W power consumption) per circuit, which is good for a system powered by a battery. If the accuracy and temperature drift of the total

design need to be improved, then a more accurate and low temperature coefficient drift voltage reference and current source resistor should be utilized. C3 and C4 are used to improve stabilization of U1; R3 and R7 are used to provide some current limit into the U1 inverting pin; and R2 and R6 are used to slow down the rise time of the N-MOSFET when it turns on. These elements may not be needed, or some bench adjustments may be required.

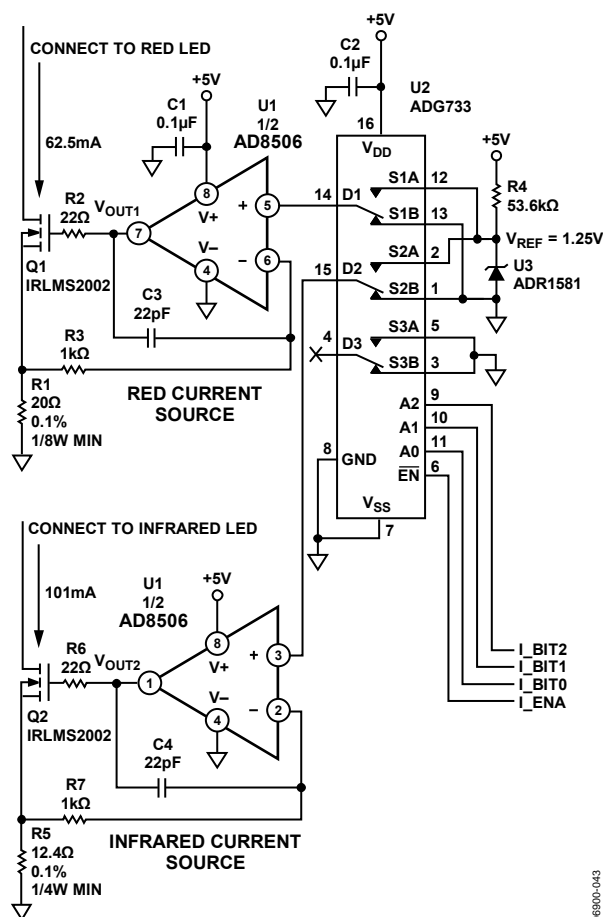


Figure 45. Pulse Oximeter Red and Infrared Current Sources Using the AD8506 as a Buffer to the Voltage Reference Device

06900-043

FOUR-POLE LOW-PASS BUTTERWORTH FILTER FOR GLUCOSE MONITOR

There are several methods of glucose monitoring: spectroscopic absorption of infrared light in the $2\ \mu\text{m}$ to $2.5\ \mu\text{m}$ range, reflectance spectrophotometry, and the amperometric type using electrochemical strips with glucose oxidase enzymes. The amperometric type generally uses three electrodes: a reference electrode, a control electrode, and a working electrode. Although this is a very old technique and widely used, signal-to-noise ratio and repeatability can be improved using the AD8506 with its low peak-to-peak voltage noise of $2.8\ \mu\text{V}$ p-p from 0.1 Hz to 10 Hz and voltage noise density of $45\ \text{nV}/\sqrt{\text{Hz}}$ at 1 kHz.

Another consideration is operation from a 3.3 V battery. Glucose signal currents are usually less than $3\ \mu\text{A}$ full scale, so the I-to-V

converter requires low input bias current. The AD8506 is an excellent choice because it provides $1\ \text{pA}$ typical and $10\ \text{pA}$ maximum of input bias current at ambient temperature.

A low-pass filter with a cutoff frequency of 80 Hz to 100 Hz is desirable in a glucose meter device to remove extraneous noise; this can be a simple two- or four-pole Butterworth. Low power op amps with bandwidths of 50 kHz to 500 kHz should be adequate. The AD8506 with its 95 kHz GBP and $15\ \mu\text{A}$ typical of current consumption meets these requirements. A circuit design of a four-pole Butterworth filter (preceded by a one-pole low-pass filter) is shown in Figure 46. With a 3.3 V battery, the total power consumption of this design is $297\ \mu\text{W}$ typical at ambient temperature.

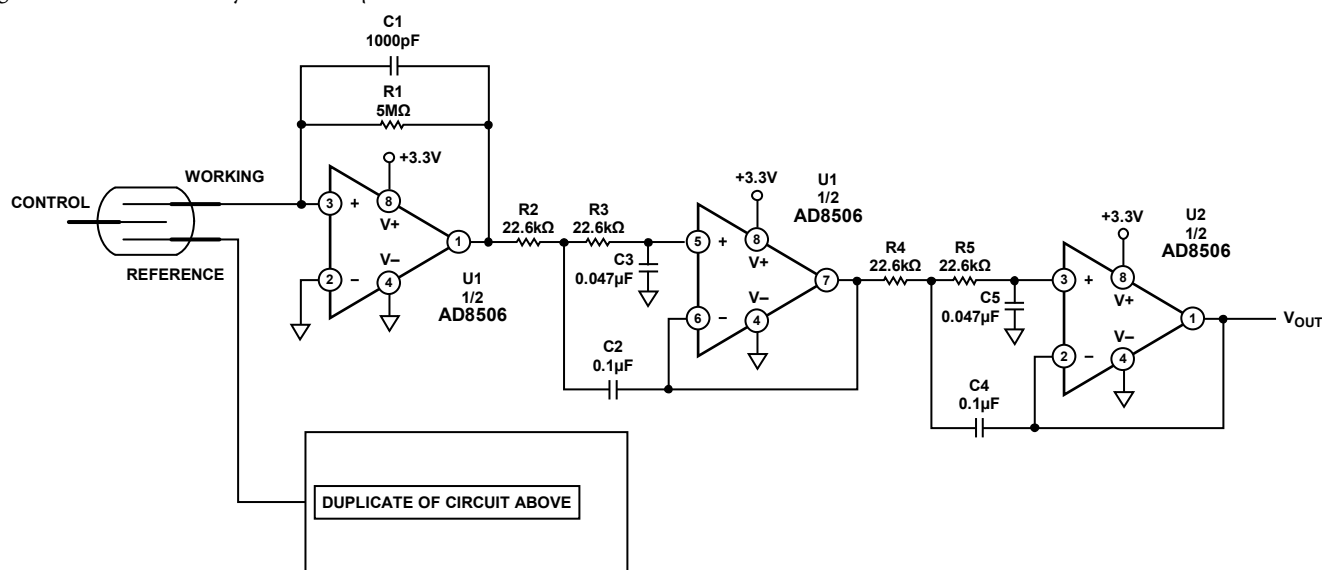
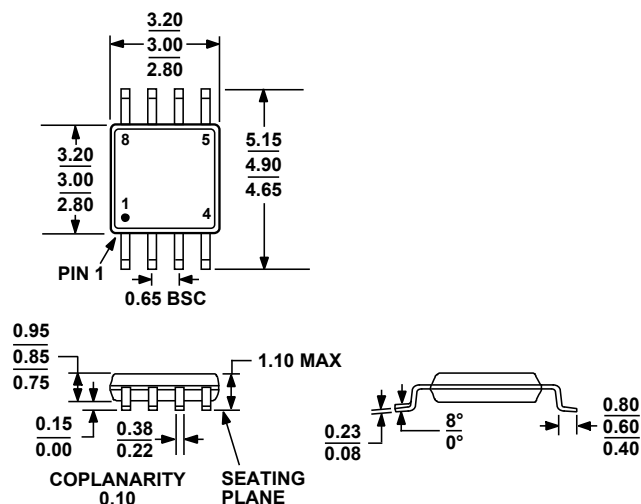


Figure 46. A Four-Pole Butterworth Filter That Can Be Used in a Glucose Meter

06900-044

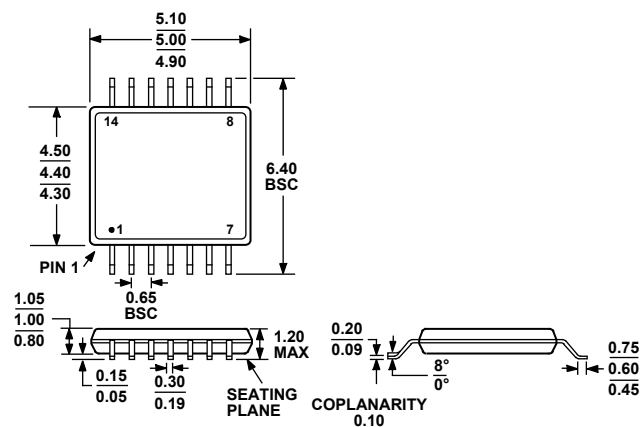
OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-187-AA

Figure 47. 8-Lead Mini Small Outline Package [MSOP]
(RM-8)

Dimensions shown in millimeters



COMPLIANT TO JEDEC STANDARDS MO-153-AB-1

Figure 48. 14-Lead Thin Shrink Small Outline Package [TSSOP]
(RU-14)

Dimensions shown in millimeters

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option	Branding
AD8506ARMZ-R2 ¹	-40°C to +125°C	8-Lead Mini Small Outline Package [MSOP]	RM-8	A1X
AD8506ARMZ-REEL ¹	-40°C to +125°C	8-Lead Mini Small Outline Package [MSOP]	RM-8	A1X
AD8508ARUZ ¹	-40°C to +125°C	14-Lead Thin Shrink Small Outline Package [TSSOP]	RU-14	
AD8508ARUZ-REEL ¹	-40°C to +125°C	14-Lead Thin Shrink Small Outline Package [TSSOP]	RU-14	

¹ Z = RoHS Compliant Part.

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