National Semiconductor

June 1, 2011

SM73307

Dual Precision, 17 MHz, Low Noise, CMOS Input Amplifier

General Description

The SM73307 is a dual, low noise, low offset, CMOS input, rail-to-rail output precision amplifier with a high gain bandwidth product. The SM73307 is ideal for a variety of instrumentation applications including solar photovoltaic.

Utilizing a CMOS input stage, the SM73307 achieves an input bias current of 100 fA, an input referred voltage noise of 5.8 $nV/\sqrt{Hz}$, and an input offset voltage of less than ±150 µV. These features make the SM73307 a superior choice for precision applications.

Consuming only 1.30 mA of supply current per channel, the SM73307 offers a high gain bandwidth product of 17 MHz, enabling accurate amplification at high closed loop gains.

The SM73307 has a supply voltage range of 1.8V to 5.5V, which makes it an ideal choice for portable low power applications with low supply voltage requirements.

The SM73307 is built with National's advanced VIP50 process technology and is offered in an 8-pin MSOP package.

The SM73307 incorporates enhanced manufacturing and support processes for the photovoltaic and automotive market, including defect detection methodologies. Reliability qualification is compliant with the requirements and temperature grades defined in the Renewable Energy Grade and AEC-Q100 standards.

Features

Unless otherwise noted, typical values at V_S = 5V.

- Renewable Energy Grade
- Input offset voltage ±150 µV (max)
- Input bias current 100 fA
- Input voltage noise 5.8 nV/√Hz
- Gain bandwidth product 17 MHz
- Supply current 1.30 mA
- Supply voltage range 1.8V to 5.5V
- THD+N @ f = 1 kHz 0.001%
- Operating temperature range −40°C to 125°C
- Rail-to-rail output swing
- 8-Pin MSOP package

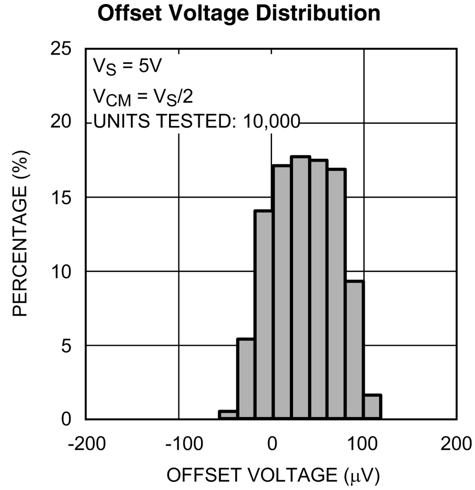
Applications

- Photovoltaic Electronics
- Active filters and buffers
- Sensor interface applications
- Transimpedance amplifiers
- Automotive

SolarMagic™ by National Semiconductor

Typical Performance

Offset Voltage Distribution



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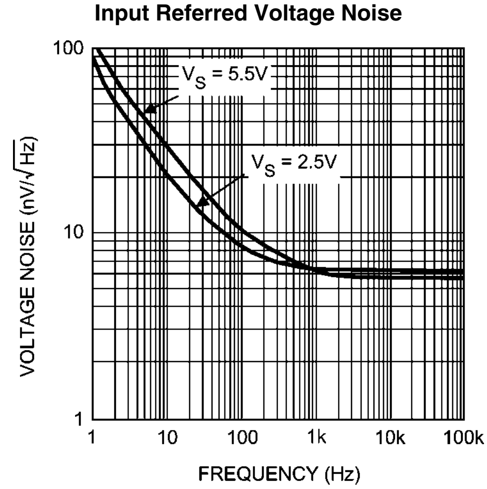
Input Referred Voltage Noise



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Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

ESD Tolerance (Note 2)	
Human Body Model	2000V
Machine Model	200V
Charge-Device Model	1000V
V_{IN} Differential	±0.3V
Supply Voltage (V_S = V+ – V−)	6.0V
Voltage on Input/Output Pins	V+ +0.3V, V− −0.3V
Storage Temperature Range	−65°C to 150°C
Junction Temperature (Note 3)	+150°C
Soldering Information	
Infrared or Convection (20 sec)	235°C
Wave Soldering Lead Temp. (10 sec)	260°C

Operating Ratings (Note 1)

Temperature Range (Note 3)	−40°C to 125°C
Supply Voltage (V_S = V+ – V−)	
0°C ≤ T_A ≤ 125°C	1.8V to 5.5V
−40°C ≤ T_A ≤ 125°C	2.0V to 5.5V
Package Thermal Resistance (θ_{JA}(Note 3))	
8-Pin MSOP	236°C/W

2.5V Electrical Characteristics

Unless otherwise specified, all limits are guaranteed for T_A = 25°C, V+ = 2.5V, V− = 0V ,V_O = V_{CM} = V+/2. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions		Min (Note 5)	Typ (Note 4)	Max (Note 5)	Units
V_{OS}	Input Offset Voltage	−20°C ≤ T_A ≤ 85°C			±20	±180 **±330**	μV
		−40°C ≤ T_A ≤ 125°C			±20	±180 **±430**	
TC V_{OS}	Input Offset Voltage Temperature Drift (Note 6, Note 8)				−1.75	±4	μV/°C
I_B	Input Bias Current	V_{CM} = 1.0V (Note 7, Note 8)	−40°C ≤ T_A ≤ 85°C		0.05	1 **25**	pA
			−40°C ≤ T_A ≤ 125°C		0.05	1 **100**	
I_{OS}	Input Offset Current	V_{CM} = 1V (Note 8)			0.006	0.5 **50**	pA
CMRR	Common Mode Rejection Ratio	0V ≤ V_{CM} ≤ 1.4V		83 **80**	100		dB
PSRR	Power Supply Rejection Ratio	2.0V ≤ V+ ≤ 5.5V V− = 0V, V_{CM} = 0		85 **80**	100		dB
		1.8V ≤ V+ ≤ 5.5V V− = 0V, V_{CM} = 0		85	98		
CMVR	Common Mode Voltage Range	CMRR ≥ 80 dB CMRR ≥ 78 dB		−0.3 **−0.3**		1.5 **1.5**	V
A_{VOL}	Open Loop Voltage Gain	V_O = 0.15 to 2.2V R_L = 2 kΩ to V+/2		84 **80**	92		dB
		V_O = 0.15 to 2.2V R_L = 10 kΩ to V+/2		90 **86**	95		
V_{OUT}	Output Voltage Swing High	R_L = 2 kΩ to V+/2			25	70 **77**	mV from either rail
		R_L = 10 kΩ to V+/2			20	60 **66**	
	Output Voltage Swing Low	R_L = 2 kΩ to V+/2			30	70 **73**	
		R_L = 10 kΩ to V+/2			15	60 **62**	

Symbol	Parameter	Conditions	Min (Note 5)	Typ (Note 4)	Max (Note 5)	Units
I_{OUT}	Output Current	Sourcing to V− V_{IN} = 200 mV (Note 9)	36 **30**	52		mA
		Sinking to V+ V_{IN} = −200 mV (Note 9)	7.5 **5.0**	15		
I_S	Supply Current	Per Channel		1.10	1.50 **1.85**	mA
SR	Slew Rate	A_V = +1, Rising (10% to 90%)		8.3		V/µs
		A_V = +1, Falling (90% to 10%)		10.3		
GBW	Gain Bandwidth			14		MHz
e_n	Input Referred Voltage Noise Density	f = 400 Hz		6.8		$nV/\sqrt{Hz}$
		f = 1 kHz		5.8		
i_n	Input Referred Current Noise Density	f = 1 kHz		0.01		$pA/\sqrt{Hz}$
THD+N	Total Harmonic Distortion + Noise	f = 1 kHz, A_V = 1, R_L = 100 kΩ V_O = 0.9 V_{PP}		0.003		%
		f = 1 kHz, A_V = 1, R_L = 600Ω V_O = 0.9 V_{PP}		0.004		

5V Electrical Characteristics

Unless otherwise specified, all limits are guaranteed for T_A = 25°C, V+ = 5V, V− = 0V, V_{CM} = V+/2. **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 5)	Typ (Note 4)	Max (Note 5)	Units
V_{OS}	Input Offset Voltage	−20°C ≤ T_A ≤ 85°C		±10	±150 **±300**	µV
		−40°C ≤ T_A ≤ 125°C		±10	±150 **±400**	
TC V_{OS}	Input Offset Voltage Temperature Drift (Note 6, Note 8)			−1.75	±4	µV/°C
I_B	Input Bias Current	V_{CM} = 2.0V (Note 7, Note 8), −40°C ≤ T_A ≤ 85°C		0.1	1 **25**	pA
		V_{CM} = 2.0V (Note 7, Note 8), −40°C ≤ T_A ≤ 125°C		0.1	1 **100**	
I_{OS}	Input Offset Current	V_{CM} = 2.0V (Note 8)		0.01	0.5 **50**	pA
CMRR	Common Mode Rejection Ratio	0V ≤ V_{CM} ≤ 3.7V	85 **82**	100		dB
PSRR	Power Supply Rejection Ratio	2.0V ≤ V+ ≤ 5.5V V− = 0V, V_{CM} = 0	85 **80**	100		dB
		1.8V ≤ V+ ≤ 5.5V V− = 0V, V_{CM} = 0	85	98		
CMVR	Common Mode Voltage Range	CMRR ≥ 80 dB CMRR ≥ 78 dB	−0.3 **−0.3**		4 **4**	V
A_{VOL}	Open Loop Voltage Gain	V_O = 0.3 to 4.7V R_L = 2 kΩ to V+/2	84 **80**	90		dB
		V_O = 0.3 to 4.7V R_L = 10 kΩ to V+/2	90 **86**	95		

Symbol	Parameter	Conditions	Min (Note 5)	Typ (Note 4)	Max (Note 5)	Units
V_{OUT}	Output Voltage Swing High	R_L = 2 kΩ to V+/2		32	70 **77**	mV from either rail
		R_L = 10 kΩ to V+/2		22	60 **66**	
	Output Voltage Swing Low	R_L = 2 kΩ to V+/2		45	75 **78**	
		R_L = 10 kΩ to V+/2		20	60 **62**	
I_{OUT}	Output Current	Sourcing to V− V_{IN} = 200 mV (Note 9)	46 **38**	66		mA
		Sinking to V+ V_{IN} = −200 mV (Note 9)	10.5 **6.5**	23		
I_S	Supply Current	(per channel)		1.30	1.70 **2.05**	mA
SR	Slew Rate	A_V = +1, Rising (10% to 90%)	6.0	9.5		V/μs
		A_V = +1, Falling (90% to 10%)	7.5	11.5		
GBW	Gain Bandwidth			17		MHz
e_n	Input Referred Voltage Noise Density	f = 400 Hz		7.0		$nV/\sqrt{Hz}$
		f = 1 kHz		5.8		
i_n	Input Referred Current Noise Density	f = 1 kHz		0.01		$pA/\sqrt{Hz}$
THD+N	Total Harmonic Distortion + Noise	f = 1 kHz, A_V = 1, R_L = 100 kΩ V_O = 4 V_{PP}		0.001		%
		f = 1 kHz, A_V = 1, R_L = 600Ω V_O = 4 V_{PP}		0.004		

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics Tables.

Note 2: Human Body Model, applicable std. MIL-STD-883, Method 3015.7. Machine Model, applicable std. JESD22-A115-A (ESD MM std. of JEDEC)
Field-Induced Charge-Device Model, applicable std. JESD22-C101-C (ESD FICDM std. of JEDEC).

Note 3: The maximum power dissipation is a function of $T_{J(MAX)}$, θ_{JA}. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A)/\theta_{JA}$. All numbers apply for packages soldered directly onto a PC Board.

Note 4: Typical values represent the most likely parametric norm as determined at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not guaranteed on shipped production material.

Note 5: Limits are 100% production tested at 25°C. Limits over the operating temperature range are guaranteed through correlations using the Statistical Quality Control (SQC) method.

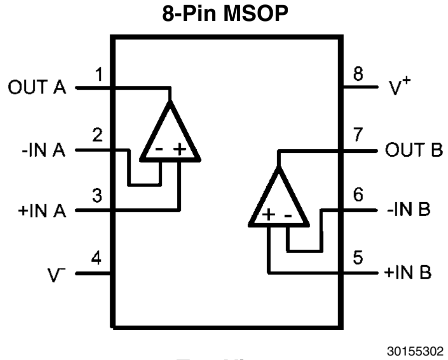
Note 6: Offset voltage average drift is determined by dividing the change in V_{OS} at the temperature extremes by the total temperature change.

Note 7: Positive current corresponds to current flowing into the device.

Note 8: This parameter is guaranteed by design and/or characterization and is not tested in production.

Note 9: The short circuit test is a momentary open loop test.

Connection Diagram



Top View

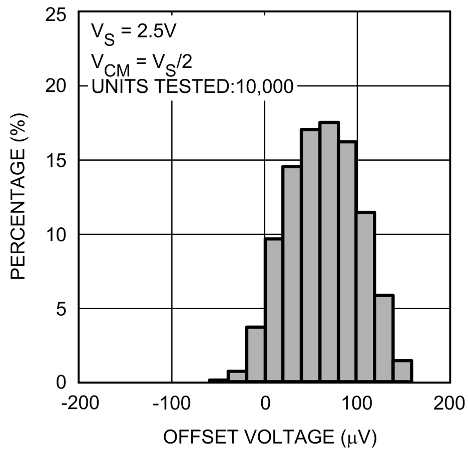
Ordering Information

Package	Part Number	Package Marking	Transport Media	NSC Drawing	Features
8–Pin MSOP	SM73307MM	S307	1k Units Tape and Reel	MUA08A	Renewable Energy Grade
	SM73307MME		250 Units Tape and Reel		
	SM73307MMX		3.5k Units Tape and Reel		

Typical Performance Characteristics

Unless otherwise noted: $T_A = 25°C$, $V_S = 5V$, $V_{CM} = V_S/2$.

Offset Voltage Distribution



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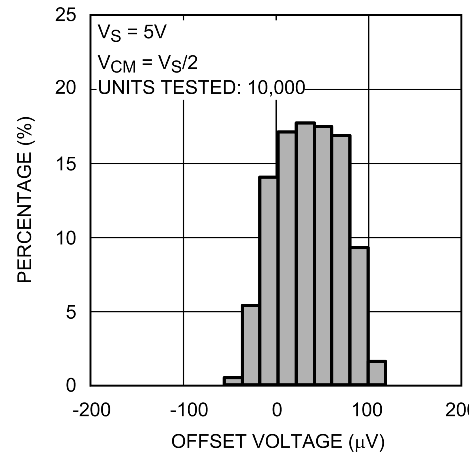
Offset Voltage Distribution



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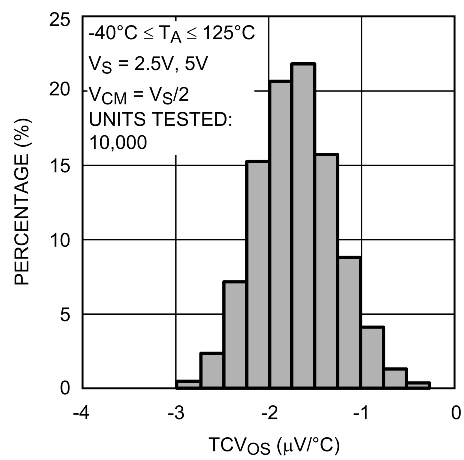
TCV_{OS} Distribution



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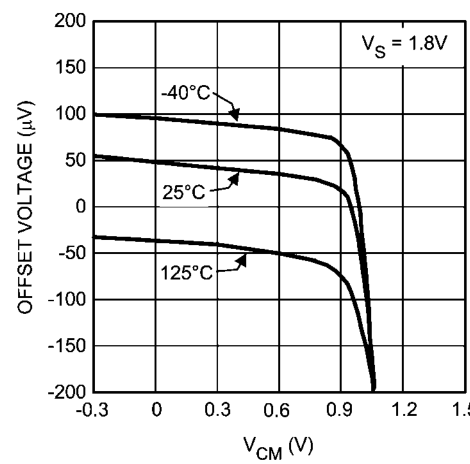
Offset Voltage vs. V_{CM}



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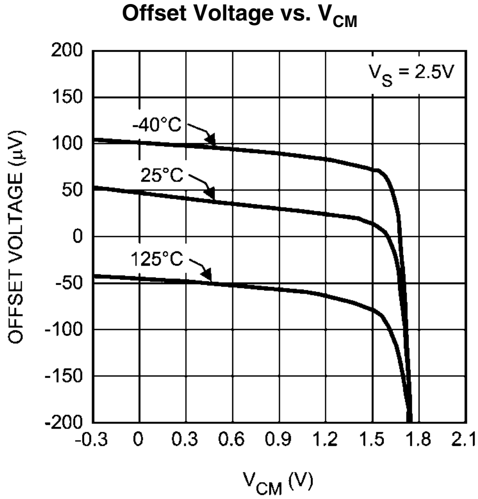
Offset Voltage vs. V_{CM}



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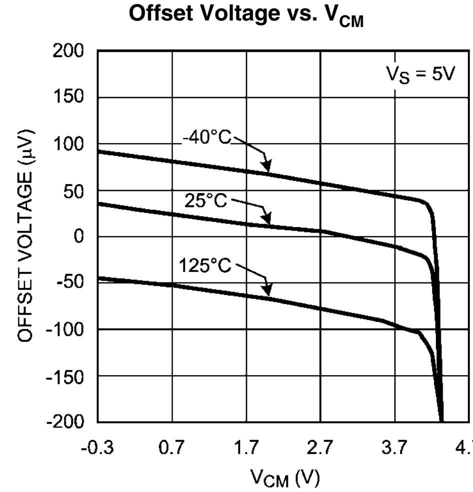
Offset Voltage vs. V_{CM}



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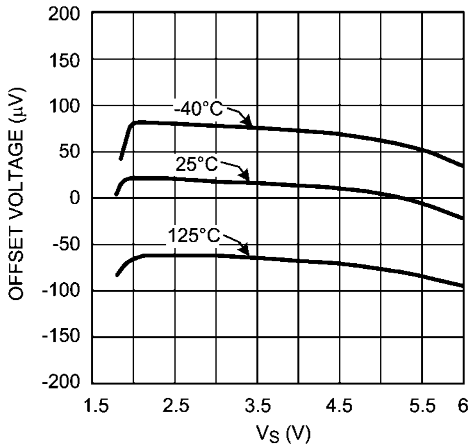
Offset Voltage vs. Supply Voltage



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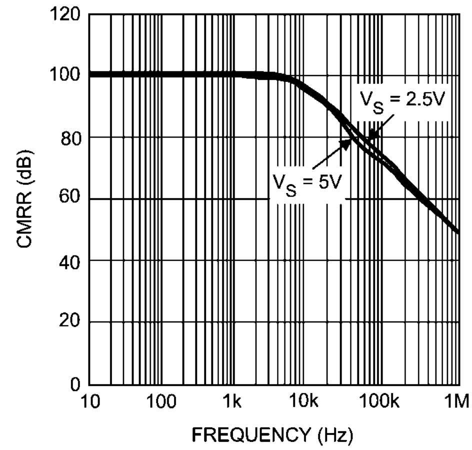
CMRR vs. Frequency



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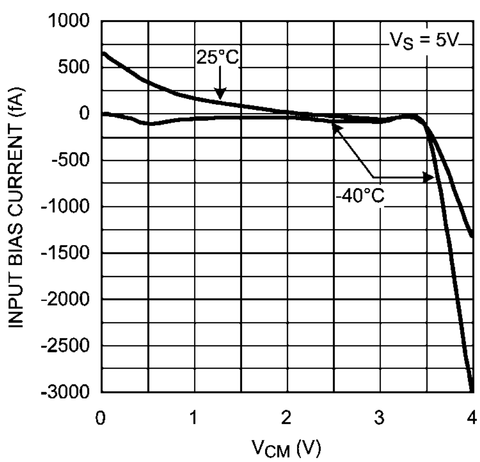
Input Bias Current vs. V_{CM}



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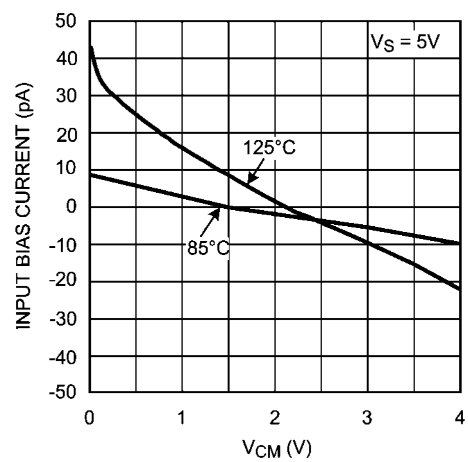
Input Bias Current vs. V_{CM}



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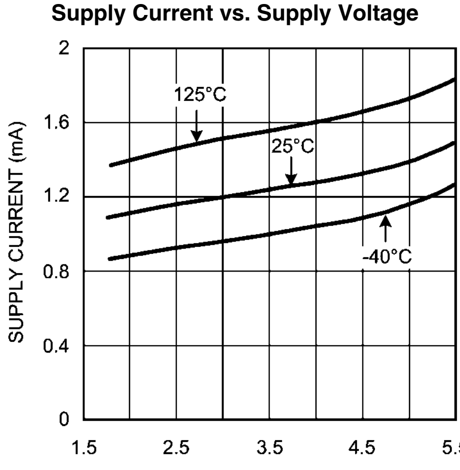
Supply Current vs. Supply Voltage



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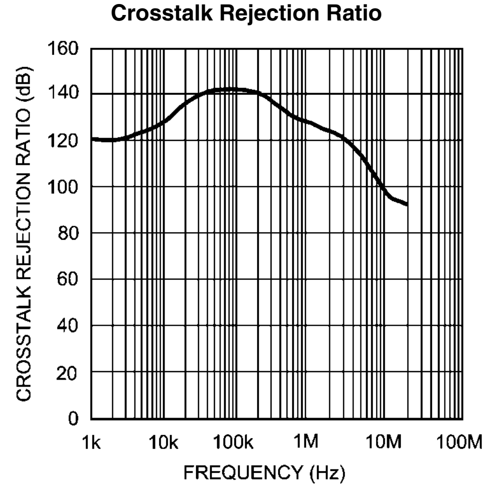
Crosstalk Rejection Ratio



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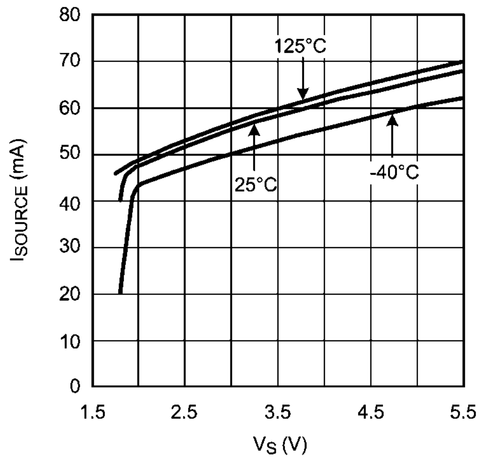
Sourcing Current vs. Supply Voltage



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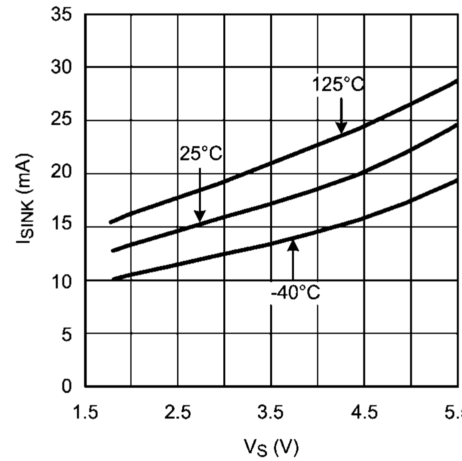
Sinking Current vs. Supply Voltage



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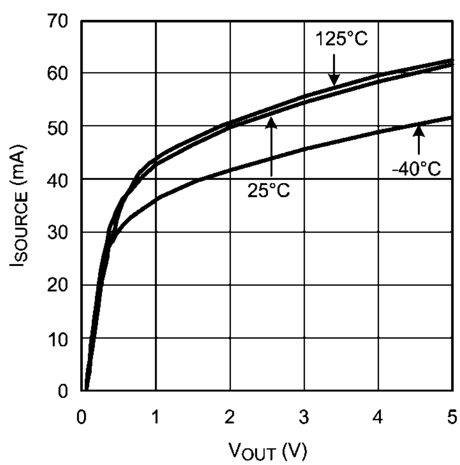
Sourcing Current vs. Output Voltage



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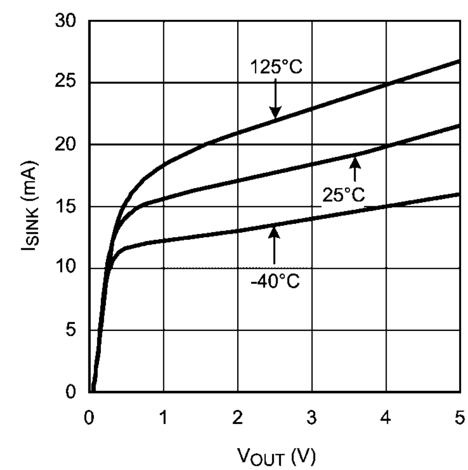
Sinking Current vs. Output Voltage



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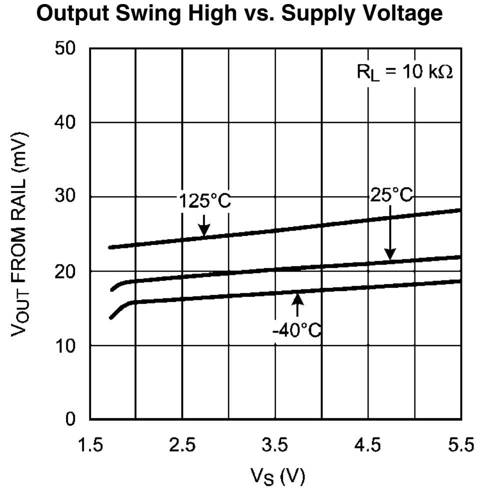
Output Swing High vs. Supply Voltage



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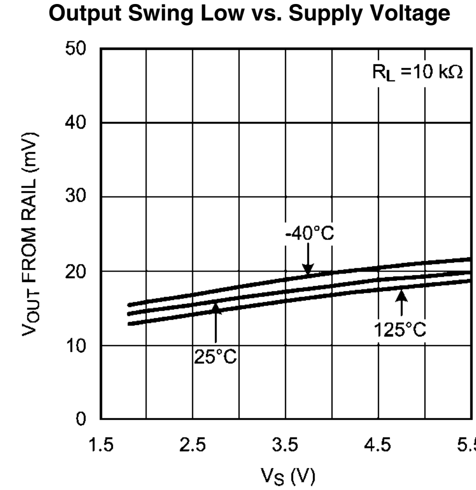
Output Swing Low vs. Supply Voltage



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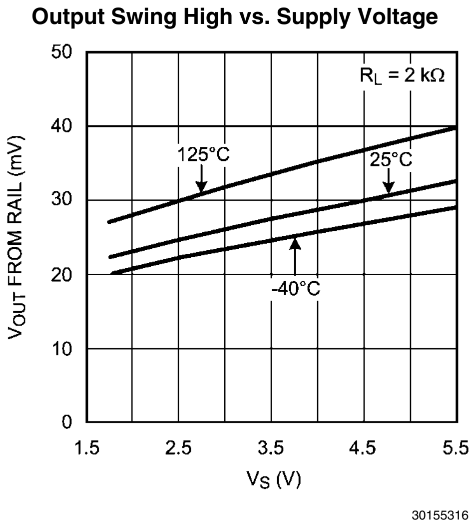
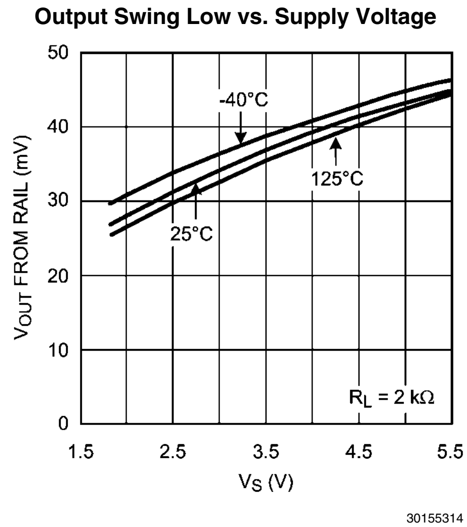
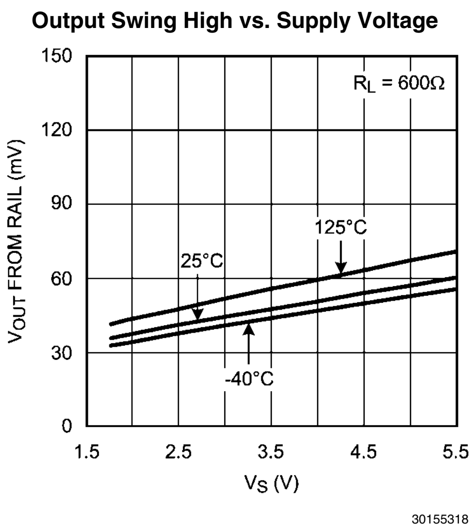
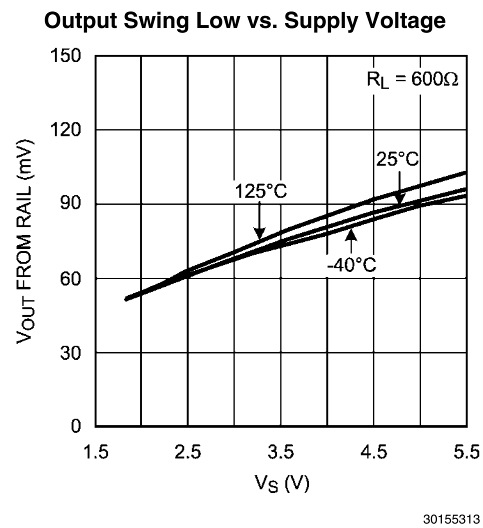
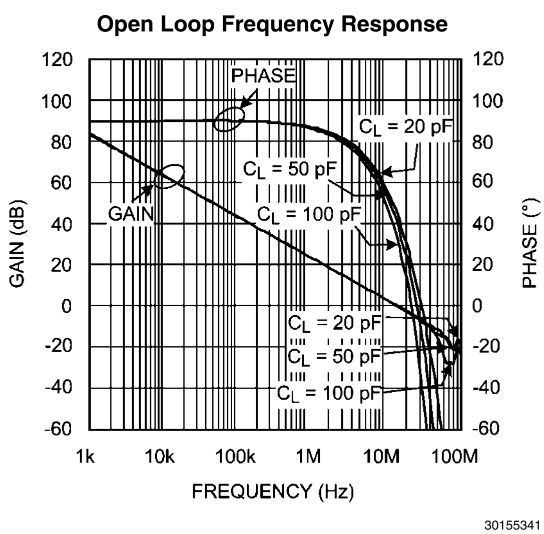
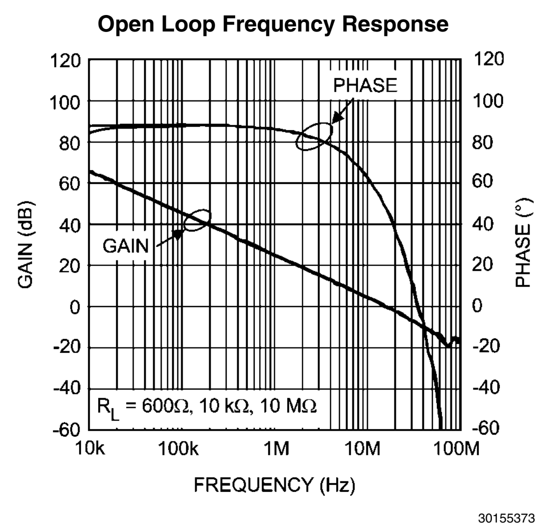

Output Swing High vs. Supply Voltage
RL = 2 kΩ
125°C
25°C
-40°C
VOUT FROM RAIL (mV)
VS (V)
30155316


Output Swing Low vs. Supply Voltage
-40°C
125°C
25°C
RL = 2 kΩ
VOUT FROM RAIL (mV)
VS (V)
30155314

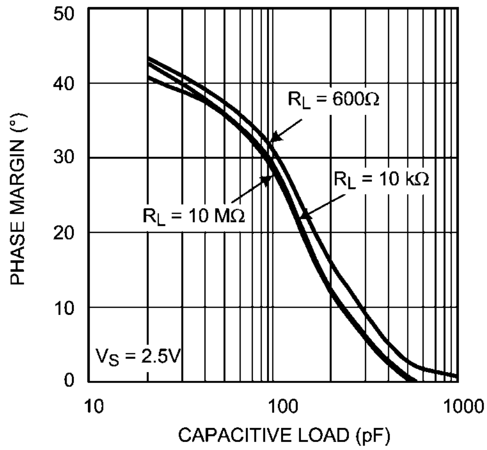

Output Swing High vs. Supply Voltage
RL = 600Ω
125°C
25°C
-40°C
VOUT FROM RAIL (mV)
VS (V)
30155318


Output Swing Low vs. Supply Voltage
RL = 600Ω
25°C
125°C
-40°C
VOUT FROM RAIL (mV)
VS (V)
30155313


Open Loop Frequency Response
PHASE
CL = 20 pF
CL = 50 pF
CL = 100 pF
GAIN
GAIN (dB)
PHASE (°)
FREQUENCY (Hz)
30155341


Open Loop Frequency Response
PHASE
GAIN
RL = 600Ω, 10 kΩ, 10 MΩ
GAIN (dB)
PHASE (°)
FREQUENCY (Hz)
30155373

Phase Margin vs. Capacitive Load



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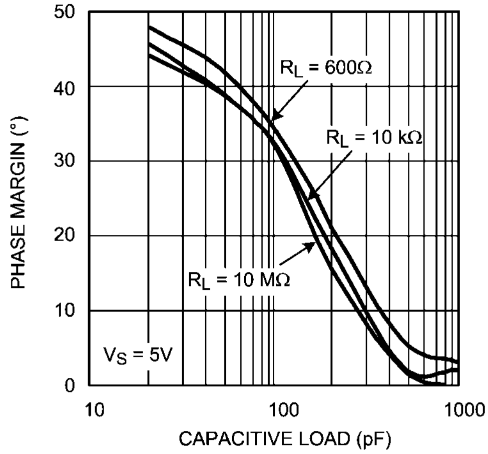
Phase Margin vs. Capacitive Load



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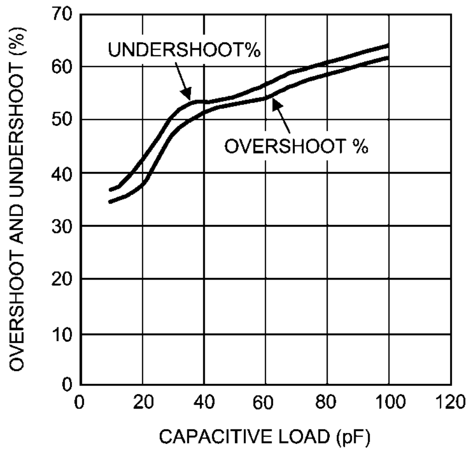
Overshoot and Undershoot vs. Capacitive Load



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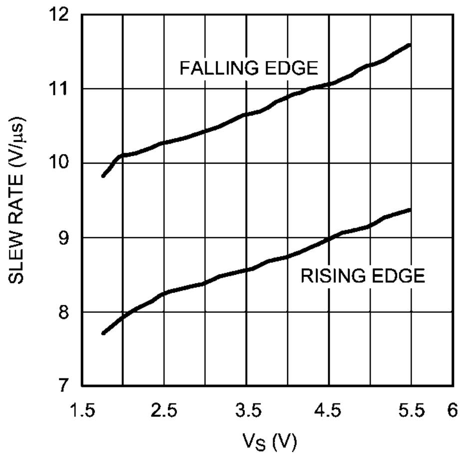
Slew Rate vs. Supply Voltage



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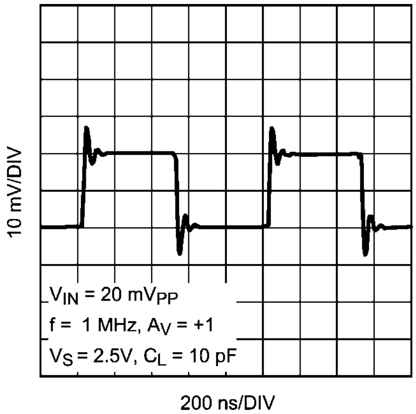
Small Signal Step Response



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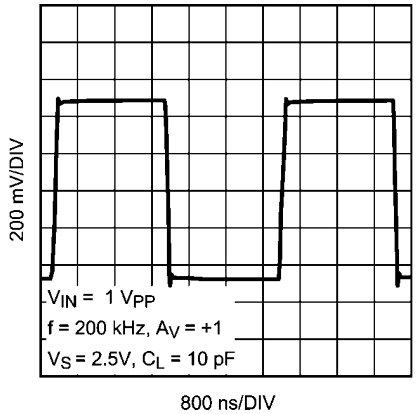
Large Signal Step Response



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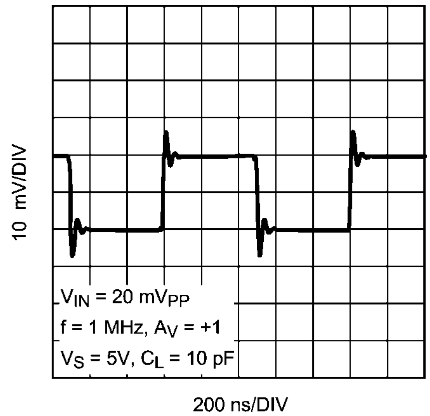
Small Signal Step Response



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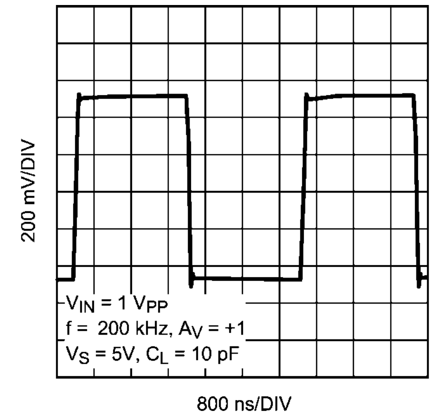
Large Signal Step Response



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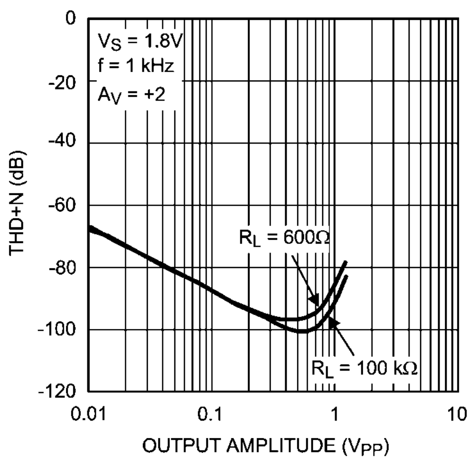
THD+N vs. Output Voltage



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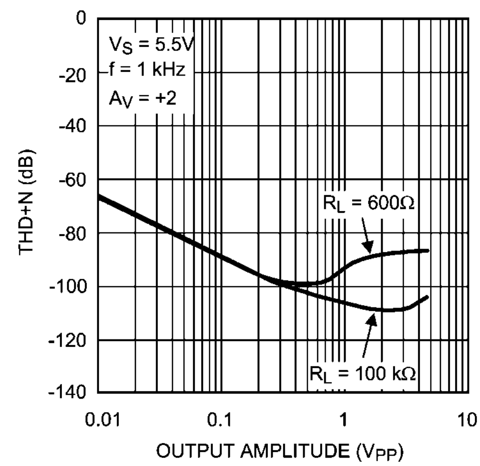
THD+N vs. Output Voltage



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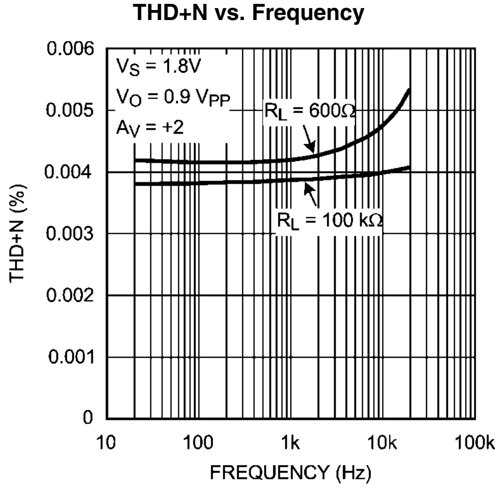
THD+N vs. Frequency



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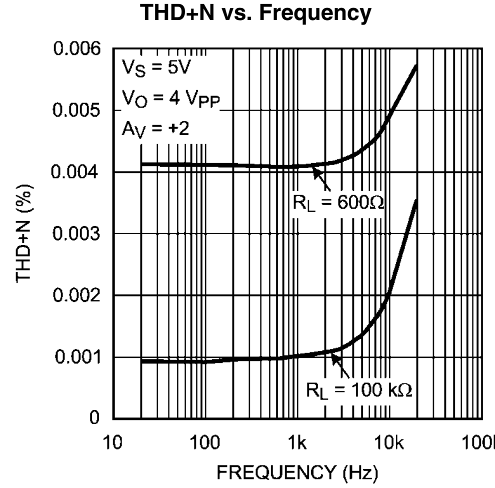

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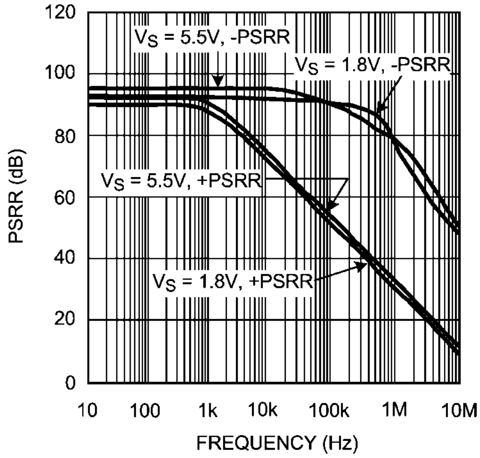
PSRR vs. Frequency



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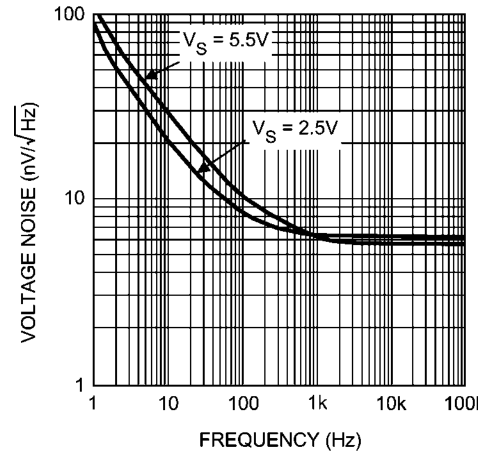
Input Referred Voltage Noise vs. Frequency



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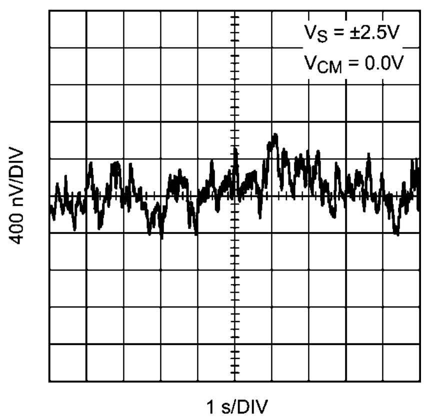
Time Domain Voltage Noise



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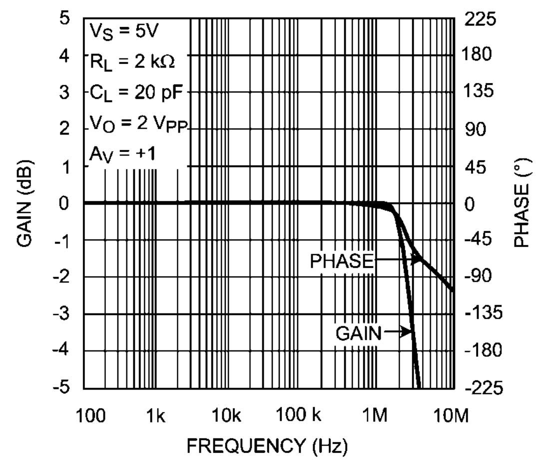
Closed Loop Frequency Response



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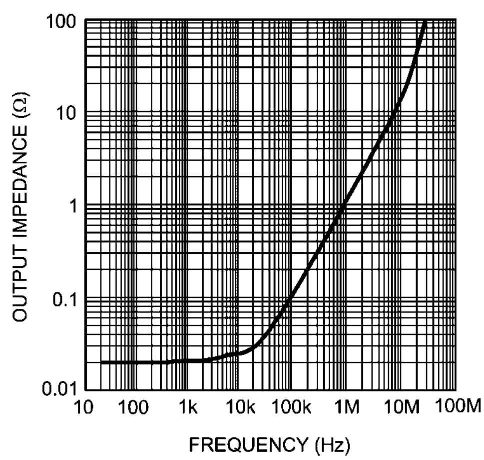
Closed Loop Output Impedance vs. Frequency



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Application Information

The SM73307 is a dual, low noise, low offset, rail-to-rail output precision amplifier with a wide gain bandwidth product of 17 MHz and low supply current. The wide bandwidth makes the SM73307 an ideal choice for wide-band amplification in photovoltaic and portable applications.

The SM73307 is superior for sensor applications. The very low input referred voltage noise of only 5.8 nV/$\sqrt{Hz}$ at 1 kHz and very low input referred current noise of only 10 fA/ $\sqrt{Hz}$ mean more signal fidelity and higher signal-to-noise ratio.

The SM73307 has a supply voltage range of 1.8V to 5.5V over a wide temperature range of 0°C to 125°C. This is optimal for low voltage commercial applications. For applications where the ambient temperature might be less than 0°C, the SM73307 is fully operational at supply voltages of 2.0V to 5.5V over the temperature range of −40°C to 125°C.

The outputs of the SM73307 swing within 25 mV of either rail providing maximum dynamic range in applications requiring low supply voltage. The input common mode range of the SM73307 extends to 300 mV below ground. This feature enables users to utilize this device in single supply applications.

The use of a very innovative feedback topology has enhanced the current drive capability of the SM73307, resulting in sourcing currents of as much as 47 mA with a supply voltage of only 1.8V.

The SM73307 is offered in an 8-pin MSOP package. This small package is an ideal solution for applications requiring minimum PC board footprint.

CAPACITIVE LOAD

The unity gain follower is the most sensitive configuration to capacitive loading. The combination of a capacitive load placed directly on the output of an amplifier along with the output impedance of the amplifier creates a phase lag which in turn reduces the phase margin of the amplifier. If phase margin is significantly reduced, the response will be either under-damped or the amplifier will oscillate.

The SM73307 can directly drive capacitive loads of up to 120 pF without oscillating. To drive heavier capacitive loads, an isolation resistor, R_{ISO} as shown in *Figure 1*, should be used. This resistor and C_L form a pole and hence delay the phase lag or increase the phase margin of the overall system. The larger the value of R_{ISO}, the more stable the output voltage will be. However, larger values of R_{ISO} result in reduced output swing and reduced output current drive.

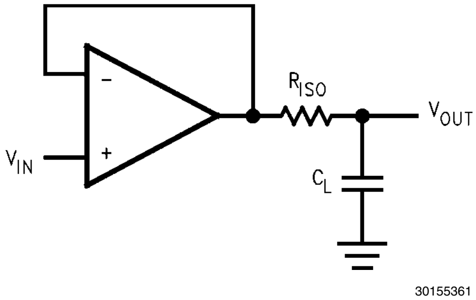


FIGURE 1. Isolating Capacitive Load

INPUT CAPACITANCE

CMOS input stages inherently have low input bias current and higher input referred voltage noise. The SM73307 enhances this performance by having the low input bias current of only 50 fA, as well as, a very low input referred voltage noise of 5.8 nV/$\sqrt{Hz}$. In order to achieve this a larger input stage has been used. This larger input stage increases the input capacitance of the SM73307. *Figure 2* shows typical input common mode capacitance of the SM73307.

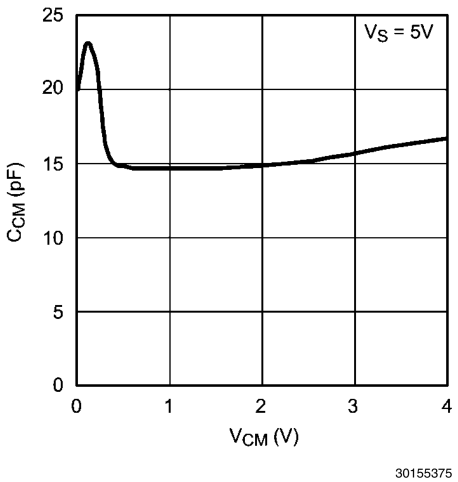
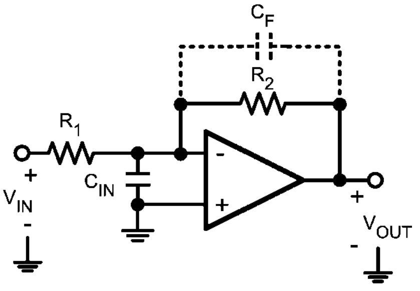


FIGURE 2. Input Common Mode Capacitance

This input capacitance will interact with other impedances, such as gain and feedback resistors which are seen on the inputs of the amplifier, to form a pole. This pole will have little or no effect on the output of the amplifier at low frequencies and under DC conditions, but will play a bigger role as the frequency increases. At higher frequencies, the presence of this pole will decrease phase margin and also cause gain peaking. In order to compensate for the input capacitance, care must be taken in choosing feedback resistors. In addition to being selective in picking values for the feedback resistor, a capacitor can be added to the feedback path to increase stability.

The DC gain of the circuit shown in *Figure 3* is simply $-R_2/R_1$.



$$A_V = -\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$$

FIGURE 3. Compensating for Input Capacitance

For the time being, ignore C_F. The AC gain of the circuit in *Figure 3* can be calculated as follows:

$$\frac{V_{OUT}}{V_{IN}}(s) = \frac{-R_2/R_1}{\left[1 + \frac{s}{\left(\frac{A_0 R_1}{R_1+R_2}\right)} + \frac{s^2}{\left(\frac{A_0}{C_{IN} R_2}\right)}\right]} \quad (1)$$

This equation is rearranged to find the location of the two poles:

$$P_{1,2} = \frac{-1}{2C_{IN}}\left[\frac{1}{R_1}+\frac{1}{R_2} \pm \sqrt{\left(\frac{1}{R_1}+\frac{1}{R_2}\right)^2 - \frac{4A_0C_{IN}}{R_2}}\right] \quad (2)$$

As shown in *Equation 2*, as the values of R_1 and R_2 are increased, the magnitude of the poles are reduced, which in turn decreases the bandwidth of the amplifier. *Figure 4* shows the frequency response with different value resistors for R_1 and R_2. Whenever possible, it is best to choose smaller feedback resistors.

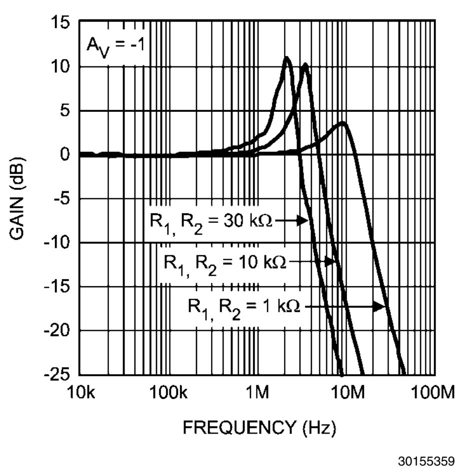


FIGURE 4. Closed Loop Frequency Response

As mentioned before, adding a capacitor to the feedback path will decrease the peaking. This is because C_F will form yet another pole in the system and will prevent pairs of poles, or complex conjugates from forming. It is the presence of pairs of poles that cause the peaking of gain. *Figure 5* shows the frequency response of the schematic presented in *Figure 3* with different values of C_F. As can be seen, using a small value capacitor significantly reduces or eliminates the peaking.

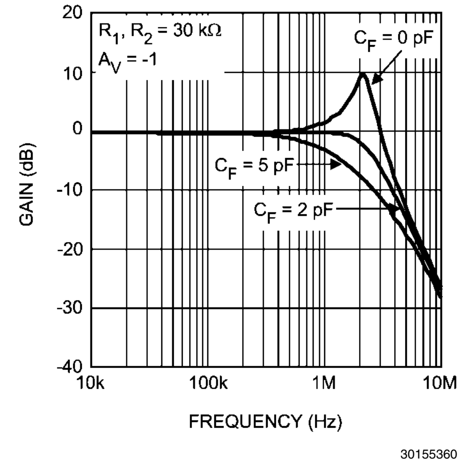


FIGURE 5. Closed Loop Frequency Response

TRANSIMPEDANCE AMPLIFIER

In many applications the signal of interest is a very small amount of current that needs to be detected. Current that is transmitted through a photodiode is a good example. Barcode scanners, light meters, fiber optic receivers, and industrial sensors are some typical applications utilizing photodiodes for current detection. This current needs to be amplified before it can be further processed. This amplification is performed using a current-to-voltage converter configuration or transimpedance amplifier. The signal of interest is fed to the inverting input of an op amp with a feedback resistor in the current path. The voltage at the output of this amplifier will be equal to the negative of the input current times the value of the feedback resistor. *Figure 6* shows a transimpedance amplifier configuration. C_D represents the photodiode parasitic capacitance and C_{CM} denotes the common-mode capacitance of the amplifier. The presence of all of these capacitances at higher frequencies might lead to less stable topologies at higher frequencies. Care must be taken when designing a transimpedance amplifier to prevent the circuit from oscillating.

With a wide gain bandwidth product, low input bias current and low input voltage and current noise, the SM73307 is ideal for wideband transimpedance applications.

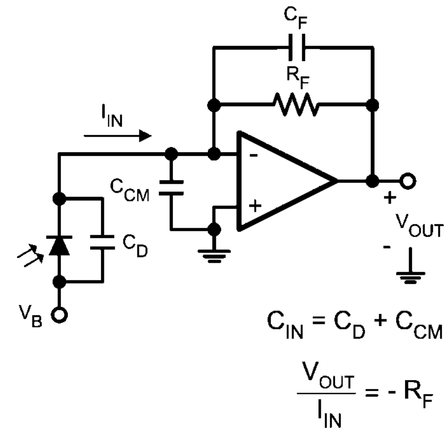


FIGURE 6. Transimpedance Amplifier

A feedback capacitance C_F is usually added in parallel with R_F to maintain circuit stability and to control the frequency response. To achieve a maximally flat, 2nd order response, R_F and C_F should be chosen by using *Equation 3*

$$C_F = \sqrt{\frac{C_{IN}}{GBWP * 2\pi R_F}} \quad (3)$$

Calculating C_F from *Equation 3* can sometimes result in capacitor values which are less than 2 pF. This is especially the case for high speed applications. In these instances, it is often more practical to use the circuit shown in *Figure 7* in order to allow more sensible choices for C_F. The new feedback capacitor, C_F', is $(1+ R_B/R_A)\ C_F$. This relationship holds as long as $R_A << R_F$.

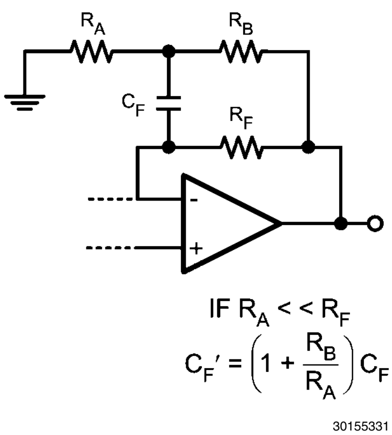


FIGURE 7. Modified Transimpedance Amplifier

SENSOR INTERFACE

The SM73307 has a low input bias current and low input referred noise, which makes it an ideal choice for sensor interfaces such as thermopiles, Infra Red (IR) thermometry, thermocouple amplifiers, and pH electrode buffers.

Thermopiles generate voltage in response to receiving radiation. These voltages are often only a few microvolts. As a result, the operational amplifier used for this application needs to have low offset voltage, low input voltage noise, and low input bias current. *Figure 8* shows a thermopile application where the sensor detects radiation from a distance and generates a voltage that is proportional to the intensity of the radiation. The two resistors, R_A and R_B, are selected to provide high gain to amplify this signal, while C_F removes the high frequency noise.

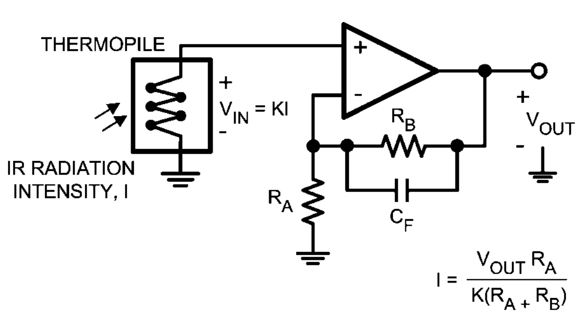


FIGURE 8. Thermopile Sensor Interface

PRECISION RECTIFIER

Rectifiers are electrical circuits used for converting AC signals to DC signals. *Figure 9* shows a full-wave precision rectifier. Each operational amplifier used in this circuit has a diode on its output. This means for the diodes to conduct, the output of the amplifier needs to be positive with respect to ground. If V_{IN} is in its positive half cycle then only the output of the bottom amplifier will be positive. As a result, the diode on the output of the bottom amplifier will conduct and the signal will show at the output of the circuit. If V_{IN} is in its negative half cycle then the output of the top amplifier will be positive, resulting in the diode on the output of the top amplifier conducting and delivering the signal from the amplifier's output to the circuit's output.

For $R_2/ R_1 \geq 2$, the resistor values can be found by using the equation shown in *Figure 9*. If $R_2/ R_1 = 1$, then R_3 should be left open, no resistor needed, and R_4 should simply be shorted.

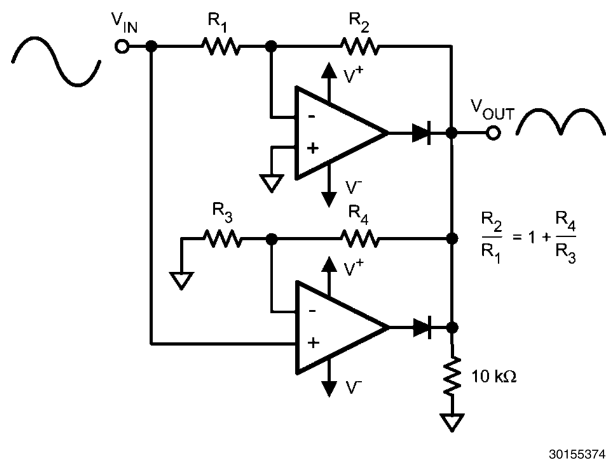
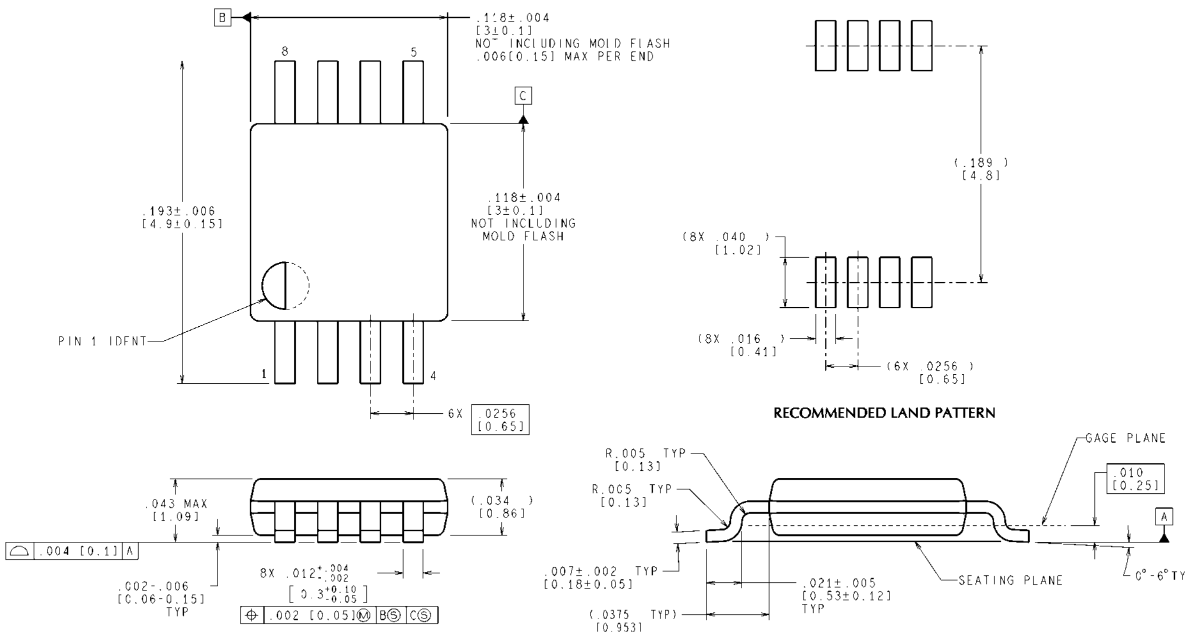


FIGURE 9. Precision Rectifier

Physical Dimensions inches (millimeters) unless otherwise noted



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VALUES IN [ ] ARE MILLIMETERS

MUA08A (Rev F)

8-Pin MSOP
NS Package Number MUA08A

Notes

Notes

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