

LMC608x 精密 CMOS 双通道运算放大器

1 特性

- (典型值, 除非另有说明)
- 低失调电压: $150 \mu\text{V}$
- 单电源运行: 4.5V 至 15.5V
- 超低输入偏置电流: 10fA
- 输出摆幅为 20mV 电源轨以内, 负载为 $2\text{k}\Omega$
- 输入共模范围包括 V^-
- 高压增益: 123dB , $2\text{k}\Omega$ 负载
- 改善了门锁效应抑制

2 应用

- 仪表放大器
- 光电二极管和红外检测器前置放大器
- 传感器放大器
- 医疗仪器
- 数模转换器 (DAC)
- 用于压电式传感器的电荷放大器

3 说明

LMC6081、LMC6082 和 LMC6084 (LMC608x) 是精密低失调电压运算放大器, 能够采用单电源供电运行。性能特性包括超低输入偏置电流、高压增益、轨到轨输出摆幅以及输入共模电压范围 (包括接地)。得益于这些特性以及低失调电压, LMC608x 非常适合精密电路应用。

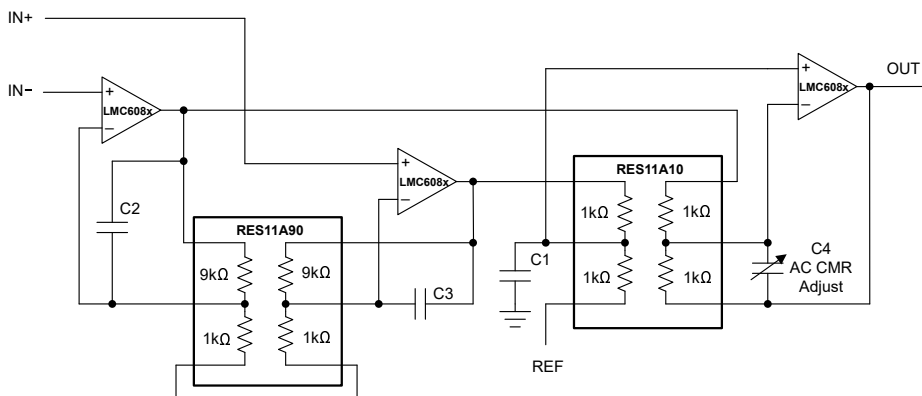
使用 LMC608x 的其他应用包括精密全波整流器、积分器、基准和采样保持电路。

有关具有更严格电源要求的设计, 请参阅 LMC6062 精密双路低功耗运算放大器。

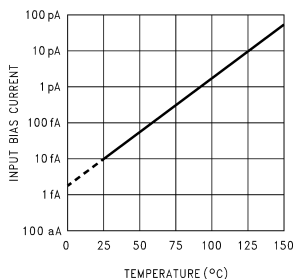
器件信息

器件型号	通道数	封装 ⁽¹⁾
LMC6081	单	D (SOIC, 8)
LMC6082	双	D (SOIC, 8)
LMC6084	四通道	D (SOIC, 14)

(1) 如需更多信息, 请参阅节 9。



仪表放大器和 RES11A



输入偏置电流与温度间的关系



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4 Pin Configuration and Functions

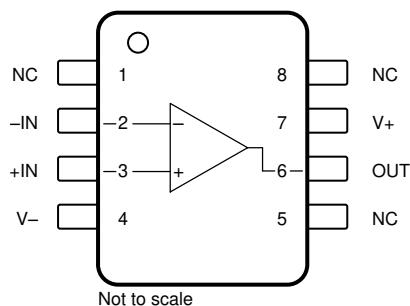


图 4-1. LMC6081 D Package, 8-Pin SOIC, and P Package, 8-Pin PDIP

表 4-1. Pin Functions: LMC6081

PIN		TYPE ⁽¹⁾	DESCRIPTION
NAME	NO.		
+IN	3	Input	Noninverting input
- IN	2	Input	Inverting input
NC	1, 5, 8	—	No internal connection (can be left floating)
OUT	6	Output	Output
V+	7	Power	Positive (highest) power supply
V -	4	Power	Negative (lowest) power supply

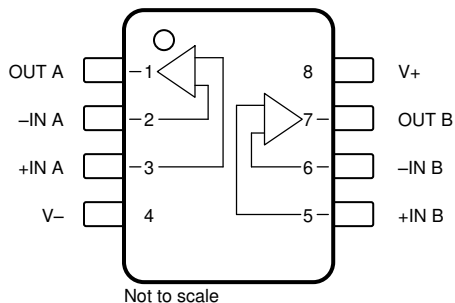


图 4-2. LMC6082 D Package, 8-Pin SOIC, and P Package, 8-Pin PDIP

表 4-2. Pin Functions: LMC6081

PIN		TYPE ⁽¹⁾	DESCRIPTION
NAME	NO.		
+IN A	3	Input	Noninverting input, channel A
- IN A	2	Input	Inverting input, channel A
+IN B	5	Input	Noninverting input, channel B
- IN B	6	Input	Inverting input, channel B
OUT A	1	Output	Output, channel A
OUT B	7	Output	Output, channel B
V+	8	Power	Positive (highest) power supply
V -	4	Power	Negative (lowest) power supply

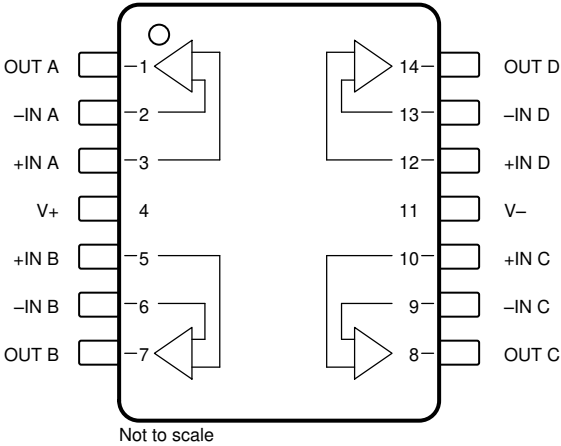


图 4-3. LMC6084 D Package, 8-Pin SOIC, and P Package, 8-Pin PDIP

表 4-3. Pin Functions: LMC6084

PIN		TYPE ⁽¹⁾	DESCRIPTION
NAME	NO.		
+IN A	3	Input	Noninverting input, channel A
+IN B	5	Input	Noninverting input, channel B
+IN C	10	Input	Noninverting input, channel C
+IN D	12	Input	Noninverting input, channel D
- IN A	2	Input	Inverting input, channel A
- IN B	6	Input	Inverting input, channel B
- IN C	9	Input	Inverting input, channel C
- IN D	13	Input	Inverting input, channel D
OUT A	1	Output	Output, channel A
OUT B	7	Output	Output, channel B
OUT C	8	Output	Output, channel C
OUT D	14	Output	Output, channel D
V+	4	Power	Positive (highest) power supply
V -	11	Power	Negative (lowest) power supply

5 Specifications

5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)^{(1) (2)}

		MIN	MAX	UNIT
Differential input voltage range		±Supply voltage		V
Supply voltage, $V_S = (V+) - (V-)$	Single supply	0	16	V
	Dual supply		±8	
Output short circuit	To V+		See ⁽³⁾	mA
	To V-		See ⁽⁴⁾	
Signal input pins	Voltage	(V-) - 0.3	(V+) + 0.3	V
	Current		±10	mA
Output pin current			±30	mA
Power supply pin current			40	mA
Temperature	Junction, T_J		150	°C
	Storage, T_{stg}	- 65	150	
Power dissipation			See ⁽⁵⁾	W

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
- (3) Do not connect output to V+, when V+ is greater than 13V or reliability is adversely affected.
- (4) Applies to both single-supply and split-supply operation. Continuous short circuit operation at elevated ambient temperature can result in exceeding the maximum allowed junction temperature of 150°C. Output currents in excess of ±30mA over long term may adversely affect reliability.
- (5) The maximum power dissipation is a function of $T_{J(Max)}$, θ_{JA} , and T_A . The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(Max)} - T_A) / \theta_{JA}$.

5.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	±2000	V

- (1) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.

5.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
Supply voltage, $V_S = (V+) - (V-)$	Single supply	4.5		15.5	V
	Dual supply	±2.25		±7.75	
Temperature range, T_J		- 40		85	°C
Power dissipation				See ⁽¹⁾	

- (1) For operating at elevated temperatures, the device must be derated based on the thermal resistance θ_{JA} with $P_D = (T_J - T_A) / \theta_{JA}$. All numbers apply for packages soldered directly into a printed circuit board.

5.4 Thermal Information LMC6081

THERMAL METRIC ⁽¹⁾		LMC6081		UNIT
		D (SOIC)	P (PDIP)	
		8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	193	115	°C/W

- (1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

5.5 Thermal Information LMC6082

THERMAL METRIC ⁽¹⁾		LMC6082		UNIT
		D (SOIC)	P (PDIP)	
		8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	193	115	°C/W

- (1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

5.6 Thermal Information LMC6084

THERMAL METRIC ⁽¹⁾		LMC6084		UNIT
		D (SOIC)	P (PDIP)	
		14 PINS	14 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	126	81	°C/W

- (1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

5.7 Electrical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$ ($V_- = 0\text{V}$), $V_{CM} = 1.5\text{V}$, $V_{OUT} = V_S / 2$, and $R_L = 1\text{M}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET VOLTAGE							
V _{OS}	Input offset voltage	LMC608xAI		±150	±350	μV	
			T _A = - 40°C to +85°C	±800			
		LMC608xI		±150	±800		
			T _A = - 40°C to +85°C	±1300			
dV _{OS} /dT	Input offset voltage drift	T _A = - 40°C to +85°C		1		μV/°C	
PSRR	Power-supply rejection ratio	Positive 5V ≤ V _{CM} ≤ 15V	LMC608xAI	75	85	dB	
			LMC608xAI T _A = - 40°C to +85°C	72			
			LMC608xI	66	85		
			LMC608xI T _A = - 40°C to +85°C	63			
		Negative - 10V ≤ V _{CM} ≤ 0V	LMC608xAI	84	94		
			LMC608xAI T _A = - 40°C to +85°C	81			
			LMC608xI	74	94		
			LMC608xI T _A = - 40°C to +85°C	71			
INPUT BIAS CURRENT							
I _B	Input bias current		±10		fA		
		T _A = - 40°C to +85°C	±4	pA			
I _{OS}	Input offset current		±5		fA		
		T _A = - 40°C to +85°C	±2	pA			
NOISE							
e _n	Input voltage noise density	f = 1kHz	22		nV/ √ Hz		
i _n	Input current noise density	f = 1kHz	4		fA/ √ Hz		
THD	Total harmonic distortion	f= 10kHz, G = - 10V/V, R _L = 2kΩ, V _{OUT} = 8V _{pp} , V _S = ±5V		0.2		%	
INPUT VOLTAGE							
V _{CM}	Common-mode voltage range	To positive rail 5V ≤ V _S ≤ 15V, CMRR > 60dB		(V+) - 1.9 (V+) - 2.3		V	
			T _A = - 40°C to +85°C	(V+) - 2.5			
		To negative rail 5V ≤ V _S ≤ 15V, CMRR > 60dB		(V-) - 0.1 (V-) - 0.4			
			T _A = - 40°C to +85°C	(V-)			
CMRR	Common-mode rejection ratio	V _S = 15V, 0V < V _{CM} < 12V	LMC608xAI	75	85	dB	
			LMC608xAI, T _A = - 40°C to +85°C	72			
			LMC608xI	66	85		
			LMC608xI, T _A = - 40°C to +85°C	63			
INPUT IMPEDANCE							
R _{IN}	Input resistance			10		TΩ	

5.7 Electrical Characteristics (续)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$ ($V_- = 0\text{V}$), $V_{CM} = 1.5\text{V}$, $V_{OUT} = V_S / 2$, and $R_L = 1\text{M}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OPEN-LOOP GAIN							
A _{OL}	Open-loop voltage gain	Sourcing, V _S = 15V, V _{CM} = 7.5V, 7.5V < V _O < 11.5V, R _L = 2k Ω	LMC608xAI	400	1400		V/mV
			LMC608xAI, T _A = - 40°C to +85°C	300			
			LMC608xI	300	1400		
			LMC608xI, T _A = - 40°C to +85°C	200			
		Sinking, V _S = 15V, V _{CM} = 7.5V, 2.5V < V _O < 7.5V, R _L = 2k Ω	LMC608xAI	180	350		
			LMC608xAI, T _A = - 40°C to +85°C	100			
			LMC608xI	90	350		
			LMC608xI, T _A = - 40°C to +85°C	60			
		Sourcing, V _S = 15V, V _{CM} = 7.5V, 7.5V < V _O < 11.5V, R _L = 600 Ω	LMC608xAI	400	1200		
			LMC608xAI, T _A = - 40°C to +85°C	150			
			LMC608xI	200	1200		
			LMC608xI, T _A = - 40°C to +85°C	80			
		Sinking, V _S = 15V, V _{CM} = 7.5V, 2.5V < V _O < 7.5V, R _L = 600 Ω	LMC608xAI	100	150		
			LMC608xAI, T _A = - 40°C to +85°C	50			
			LMC608xI	70	150		
			LMC608xI, T _A = - 40°C to +85°C	35			
FREQUENCY RESPONSE							
GBW	Gain bandwidth product				1.3		MHz
SR	Slew rate ⁽²⁾	V _S = 15V, 10V step		0.8	1.5		V/μs
			T _A = - 40°C to +85°C	0.6			
θ _m	Phase margin				50		°
	Crosstalk	Dual and quad channel, V _S = 15V, R _L = 100kΩ to 7.5V, f = 1kHz, V _{OUT} = 12V _{pp}			140		dB

5.7 Electrical Characteristics (续)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$ ($V_- = 0\text{V}$), $V_{CM} = 1.5\text{V}$, $V_{OUT} = V_S / 2$, and $R_L = 1\text{M}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT	
OUTPUT								
V _O	Voltage output swing	Positive rail V _S = 5V, R _L = 2kΩ	LMC608xAI	4.80	4.87		V	
			LMC608xAI, T _A = - 40°C to +85°C	4.73				
			LMC608xI	4.75	4.87			
			LMC608xI, T _A = - 40°C to +85°C	4.67				
		Negative rail V _S = 5V, R _L = 2kΩ	LMC608xAI		0.10	0.13		
			LMC608xAI, T _A = - 40°C to +85°C			0.17		
			LMC608xI		0.10	0.20		
			LMC608xI, T _A = - 40°C to +85°C			0.24		
		Positive rail V _S = 5V, R _L = 600Ω	LMC608xAI	4.50	4.61			
			LMC608xAI, T _A = - 40°C to +85°C	4.31				
			LMC608xI	4.50	4.61			
			LMC608xI, T _A = - 40°C to +85°C	4.21				
		Negative rail V _S = 5V, R _L = 600Ω	LMC608xAI		0.30	0.40		
			LMC608xAI, T _A = - 40°C to +85°C			0.50		
			LMC608xI		0.30	0.50		
			LMC608xI, T _A = - 40°C to +85°C			0.63		
		Positive rail V _S = 15V, R _L = 2kΩ	LMC608xAI	14.50	14.63			
			LMC608xAI, T _A = - 40°C to +85°C	14.34				
			LMC608xI	14.37	14.63			
			LMC608xI, T _A = - 40°C to +85°C	14.25				
		Negative rail V _S = 15V, R _L = 2kΩ	LMC608xAI		0.26	0.35		
			LMC608xAI, T _A = - 40°C to +85°C			0.45		
			LMC608xI		0.26	0.44		
			LMC608xI, T _A = - 40°C to +85°C			0.56		
		Positive rail V _S = 15V, R _L = 600Ω	LMC608xAI	13.35	13.90			
			LMC608xAI, T _A = - 40°C to +85°C	12.86				
			LMC608xI	14.37	13.90			
			LMC608xI, T _A = - 40°C to +85°C	14.25				
		Negative rail V _S = 15V, R _L = 600Ω	LMC608xAI		0.79	1.16		
			LMC608xAI, T _A = - 40°C to +85°C			1.32		
			LMC608xI		0.79	1.33		
			LMC608xI, T _A = - 40°C to +85°C			1.58		

5.7 Electrical Characteristics (续)

at $T_A = 25^\circ\text{C}$, $V_S = 5\text{V}$ ($V_- = 0\text{V}$), $V_{CM} = 1.5\text{V}$, $V_{OUT} = V_S / 2$, and $R_L = 1\text{M}\Omega$ connected to $V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
I _{SC}	Short-circuit current	Sourcing V _S = 5V, V _{OUT} = 0V	LMC608xAI	16	22		mA
			LMC608xAI, T _A = - 40°C to +85°C	10			
			LMC608xI	13	22		
			LMC608xI, T _A = - 40°C to +85°C	8			
		Sinking V _S = 5V, V _{OUT} = 5V	LMC608xAI	16	21		
			LMC608xAI, T _A = - 40°C to +85°C	13			
			LMC608xI	13	21		
			LMC608xI, T _A = - 40°C to +85°C	10			
		Sourcing V _S = 15V, V _{OUT} = 0V	LMC608xAI	28	30		
			LMC608xAI, T _A = - 40°C to +85°C	22			
			LMC608xI	23	30		
			LMC608xI, T _A = - 40°C to +85°C	18			
		Sinking V _S = 15V, V _{OUT} = 13V ⁽¹⁾	LMC608xAI	28	34		
			LMC608xAI, T _A = - 40°C to +85°C	22			
			LMC608xI	23	34		
			LMC608xI, T _A = - 40°C to +85°C	18			
POWER SUPPLY							
I _Q	Quiescent current per amplifier	V _{OUT} = 1.5V, V _S = 5V			0.45	0.75	mA
			T _A = - 40°C to +85°C			0.9	
		V _{OUT} = 7.5V, V _S = 15V LMC6082, LMC6084			0.55	0.85	
			T _A = - 40°C to +85°C			1	
		V _{OUT} = 7.5V, V _S = 15V LMC6081			0.55	0.85	
			T _A = - 40°C to +85°C			0.95	

(1) Do not connect output to V_+ , when V_+ is greater than 13V or reliability is adversely affected.

(2) Specification limit established from device population bench system measurements across multiple lots. Number specified is the slower of the positive and negative slew rates.

5.8 Typical Characteristics

at $T_A = 25^\circ\text{C}$, $V_S = \pm 7.5\text{V}$, $V_{OUT} = \text{mid-supply}$, and $R_L \geq 1\text{M}\Omega$ (unless otherwise specified)

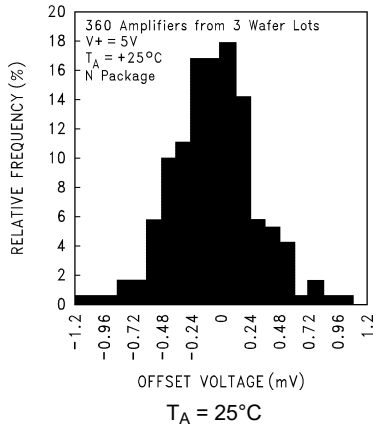


图 5-1. Distribution of LMC6082 Input Offset Voltage

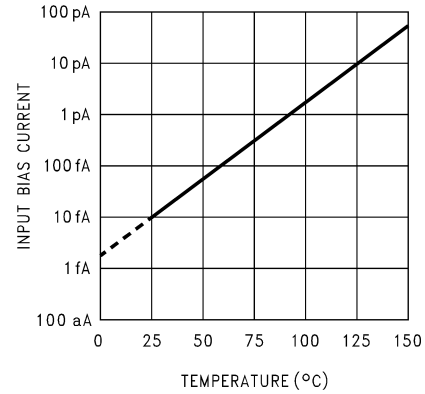


图 5-2. Input Bias Current vs Temperature

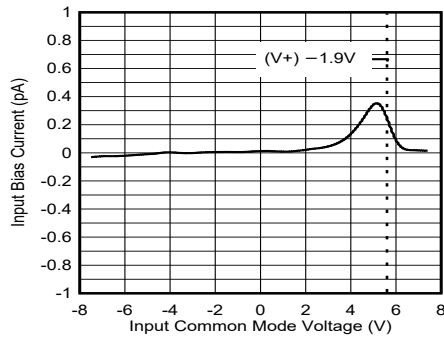


图 5-3. Input Bias Current vs Common-Mode Voltage

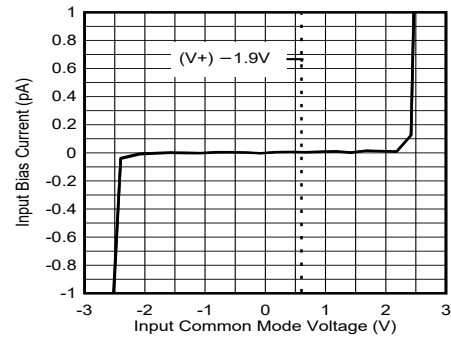


图 5-4. Input Bias Current vs Common-Mode Voltage

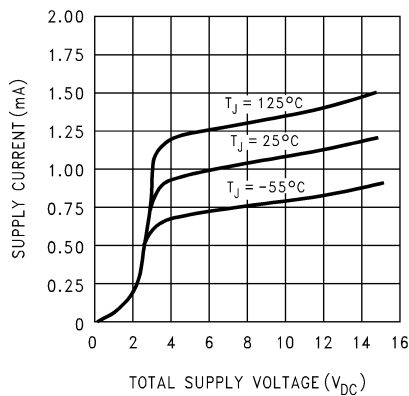


图 5-5. Supply Current vs Supply Voltage

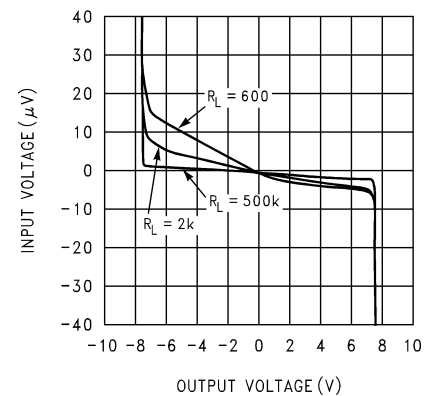


图 5-6. Input Voltage vs Output Voltage

5.8 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 7.5\text{V}$, $V_{OUT} = \text{mid-supply}$, and $R_L \geq 1\text{M}\Omega$ (unless otherwise specified)

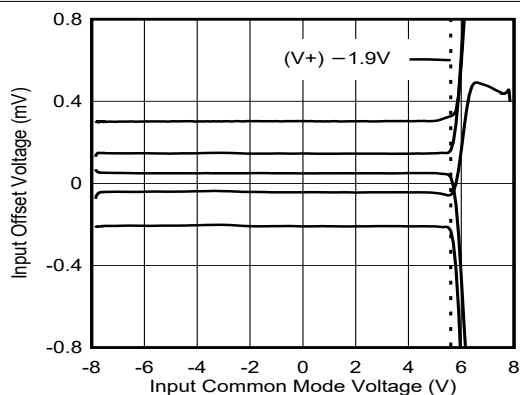


图 5-7. Input Offset Voltage vs Common Mode Voltage

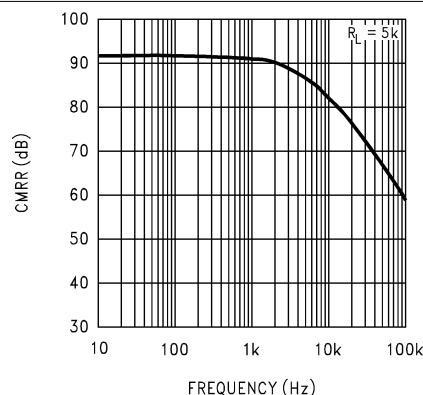


图 5-8. Common Mode Rejection Ratio vs Frequency

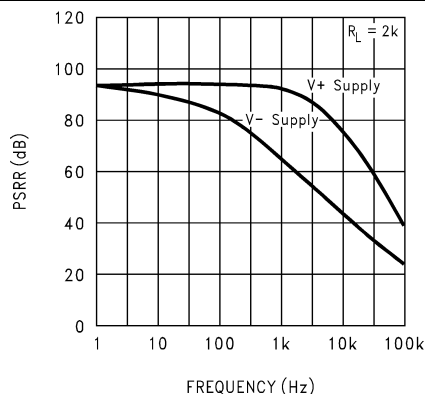


图 5-9. Power Supply Rejection Ratio vs Frequency

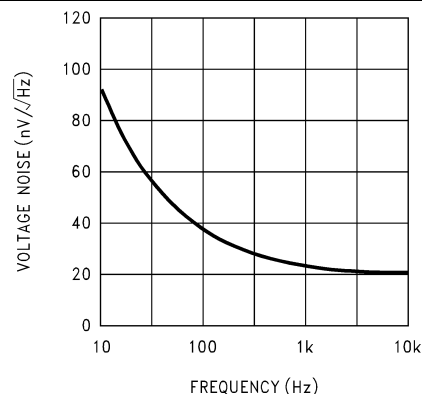


图 5-10. Input Voltage Noise vs Frequency

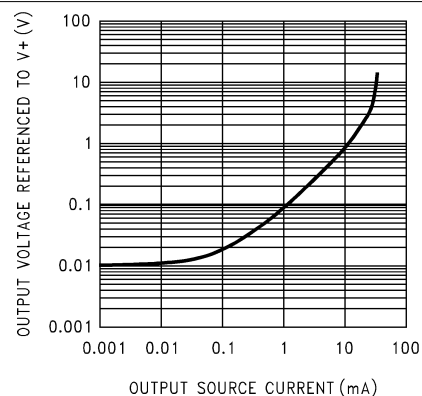


图 5-11. Output Characteristics Sourcing Current

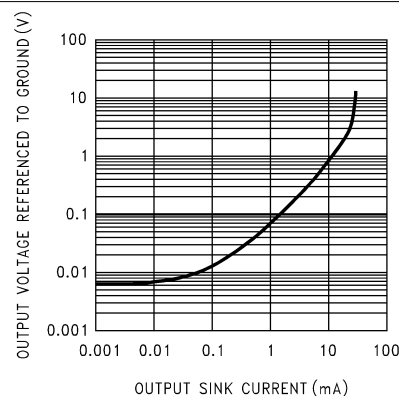


图 5-12. Output Characteristics Sinking Current

5.8 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 7.5\text{V}$, $V_{OUT} = \text{mid-supply}$, and $R_L \geq 1\text{M}\Omega$ (unless otherwise specified)

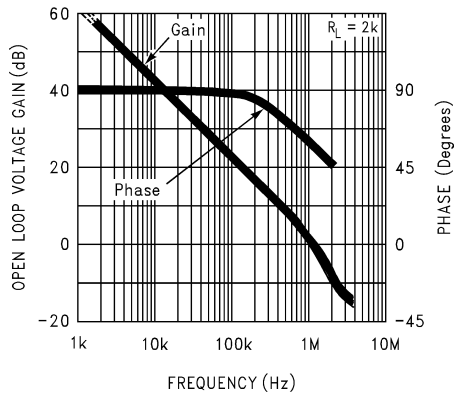


图 5-13. Gain and Phase Response vs Temperature

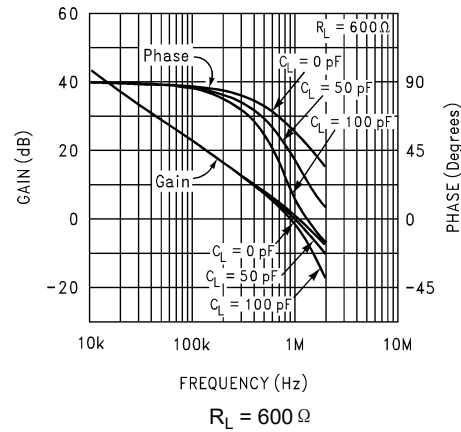


图 5-14. Gain and Phase Response vs Capacitive Load

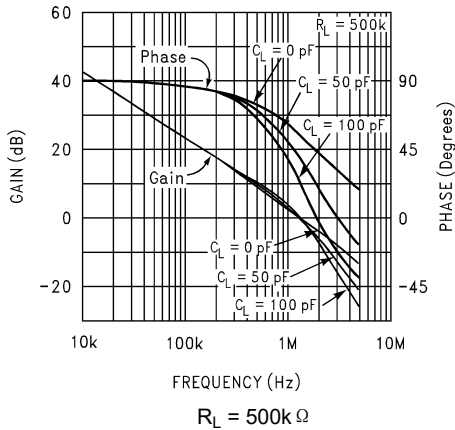


图 5-15. Gain and Phase Response vs Capacitive Load

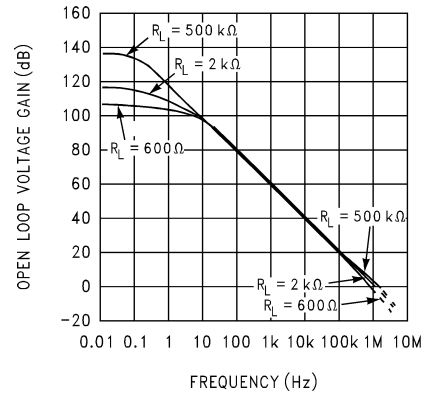


图 5-16. Open-Loop Frequency Response

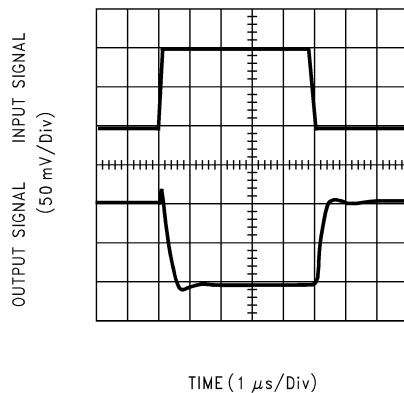


图 5-17. Inverting Small-Signal Pulse Response

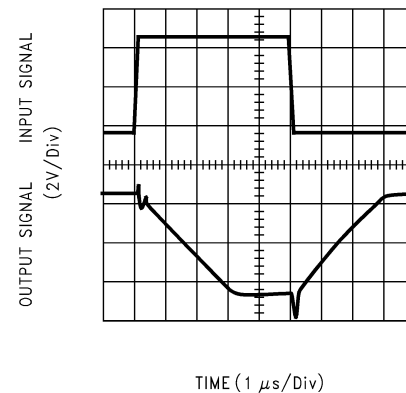


图 5-18. Inverting Large-Signal Pulse Response

5.8 Typical Characteristics (continued)

at $T_A = 25^\circ\text{C}$, $V_S = \pm 7.5\text{V}$, $V_{OUT} = \text{mid-supply}$, and $R_L \geq 1\text{M}\Omega$ (unless otherwise specified)

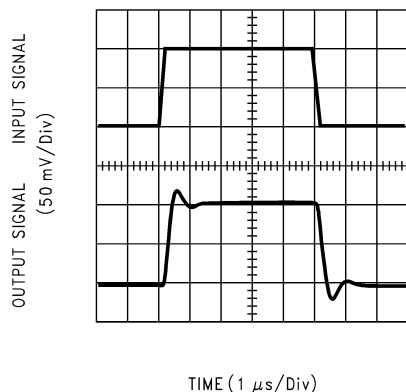


图 5-19. Noninverting Small-Signal Pulse Response

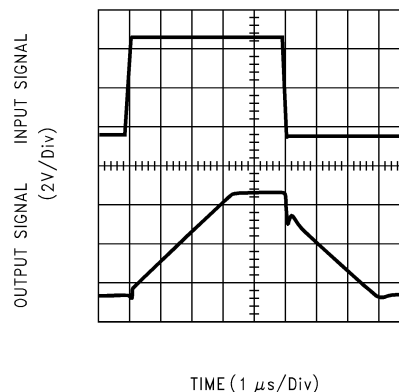


图 5-20. Noninverting Large-Signal Pulse Response

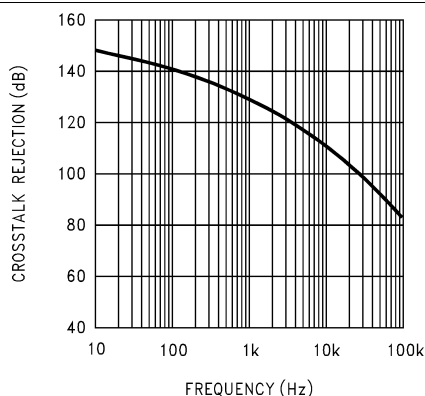


图 5-21. Crosstalk Rejection vs Frequency

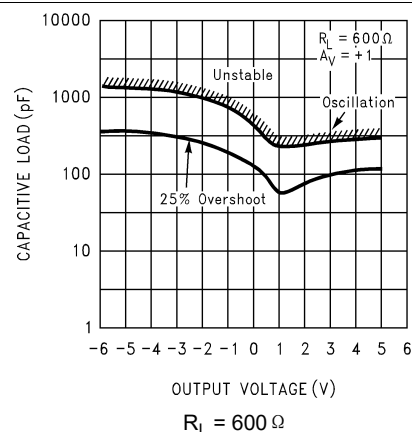


图 5-22. Stability vs Capacitive Load

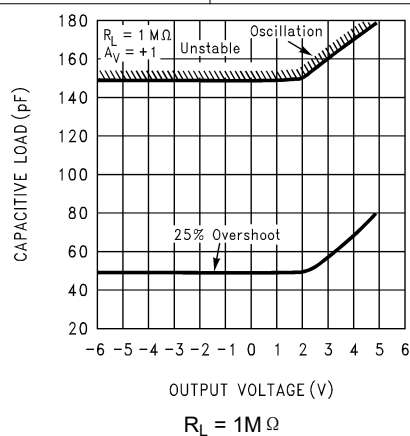


图 5-23. Stability vs Capacitive Load

6 Application and Implementation

备注

以下应用部分中的信息不属于 TI 器件规格的范围，TI 不担保其准确性和完整性。TI 的客户应负责确定器件是否适用于其应用。客户应验证并测试其设计，以确保系统功能。

6.1 Application Information

6.1.1 Amplifier Topology

The LMC608x incorporate a novel op amp design topology that enables rail to rail output swing even when driving a large load. The topology provides both low output impedance and large gain. Special compensation design techniques are incorporated to maintain stability over a wider range of operating conditions than traditional micropower op amps. These features make the LMC608x both easier to design with, and provide higher speed than products typically found in this ultra-low power class. The LMC608x provide a wide input common-mode voltage range extending to the negative supply. In the presence of large input common-mode voltages, input bias current performance can be degraded. Large common-mode voltages are uncommon in very low leakage designs.

6.1.2 Compensating for Input Capacitance

The use of large value feedback resistors is quite common for amplifiers with ultra-low input current, like the LMC608x.

Although the LMC608x are highly stable over a wide range of operating conditions, certain precautions must be met to achieve the desired pulse response when a large feedback resistor is used. Large feedback resistors and even small values of input capacitance, due to transducers, photodiodes, and circuit board parasitics, reduce phase margins.

When a high input impedance is demanded, guarding of the LMC608x is suggested. Guarding input lines not only reduces leakage, but lowers stray input capacitance as well. (See [Printed-Circuit-Board Layout for High Impedance Work](#))

The effect of input capacitance can be compensated for by adding a capacitor, C_f , around the feedback resistors (as in [图 6-1](#)) such that:

$$\frac{1}{2\pi R_1 C_{IN}} \geq \frac{1}{2\pi R_2 C_f} \quad (1)$$

or

$$R_1 C_{IN} \leq R_2 C_f \quad (2)$$

The exact value of C_{IN} can be difficult to find, so C_f can be experimentally adjusted so that the desired pulse response is achieved. Refer to the [LMC66x](#) for a more detailed discussion on compensating for input capacitance.

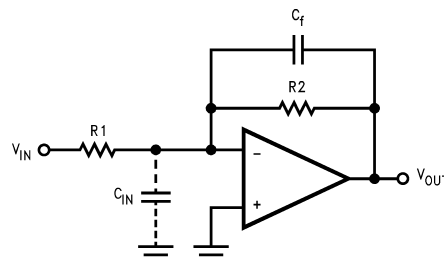


图 6-1. Canceling the Effect of Input Capacitance

6.1.3 Capacitive Load Tolerance

All rail-to-rail output swing op amps have voltage gain in the output stage. A compensation capacitor is normally included in this integrator stage. The frequency location of the dominant pole is affected by the resistive load on the amplifier. Capacitive load driving capability can be optimized by using an appropriate resistive load in parallel with the capacitive load (see 节 5.8).

Direct capacitive loading reduces the phase margin of many op amps. A pole in the feedback loop is created by the combination of the op amp output impedance and the capacitive load. This pole induces phase lag at the unity-gain crossover frequency of the amplifier resulting in either an oscillatory or underdamped pulse response. With a few external components, op amps can easily indirectly drive capacitive loads, as shown in 图 6-2.

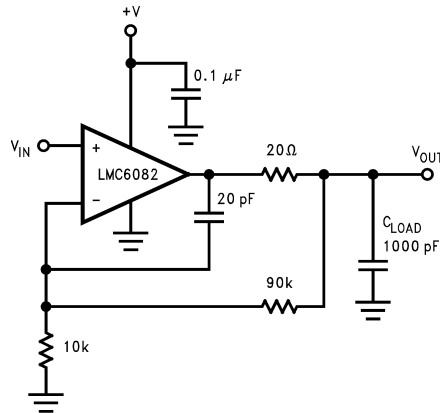


图 6-2. LMC6082 Noninverting Gain of 10 Amplifier, Compensated to Handle Capacitive Loads

In the circuit of 图 6-2, R1 and C1 serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifier inverting input, thereby preserving phase margin in the overall feedback loop.

Capacitive load driving capability is enhanced by using a pull up resistor to V^+ 图 6-3. Typically a pull up resistor conducting 500 μ A or more significantly improves capacitive load responses. The value of the pull up resistor must be determined based on the current sinking capability of the amplifier with respect to the desired output swing. Open loop gain of the amplifier can also be affected by the pullup resistor (see 节 5.7).

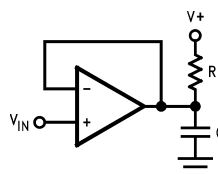


图 6-3. Compensating for Large Capacitive Loads With a Pullup Resistor

6.1.4 Latch-Up

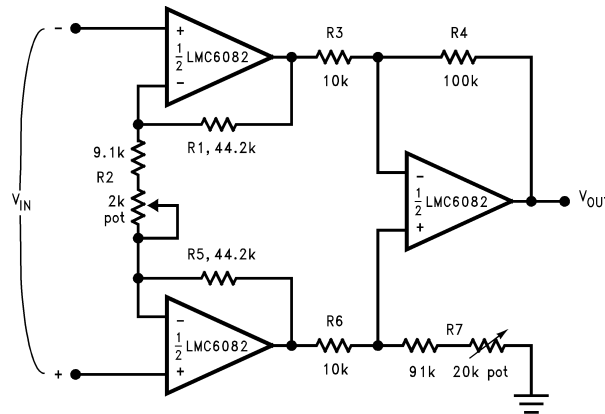
CMOS devices tend to be susceptible to latch-up as a result of the internal, parasitic, silicon-controlled rectifier (SCR) effects. The input and output (I/O) pins look similar to the gate of the SCR. A minimum current is required to trigger the SCR gate lead. Use some resistive method to isolate any capacitance from supplying excess current to the I/O pins. In addition, like an SCR, there is a minimum holding current for any latch-up mode. Limiting current to the supply pins also inhibits latch-up susceptibility.

6.2 Typical Applications

6.2.1 Typical Single-Supply Applications

The extremely high input impedance, and low power consumption, make the LMC608x an excellent choice for applications that require battery-powered operation. Examples of these types of applications are hand-held pH probes, analytic medical instruments, magnetic field detectors, gas detectors, and silicon based pressure transducers.

图 6-4 shows an instrumentation amplifier that features high differential and common mode input resistance ($> 10^{14} \Omega$), 0.01% gain accuracy at $A_V = 1000$, excellent CMRR with $1k \Omega$ imbalance in bridge source resistance. Input current is less than 100fA and offset drift is less than $2.5 \mu V/^{\circ}C$. R_2 provides a simple means of adjusting gain over a wide range without degrading CMRR. R_7 is an initial trim used to maximize CMRR without using super precision matched resistors. For good CMRR over temperature, use low drift resistors like the RES11A. An example of an instrumentation amplifier with the LMC608x is provided in the next section.



If $R_1 = R_5$, $R_3 = R_6$, and $R_4 = R_7$; then

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_2 + 2R_1}{R_2} \times \frac{R_4}{R_3} \quad (3)$$

$A_V \approx 100$ for circuit shown ($R_2 = 9.822k \Omega$).

图 6-4. Instrumentation Amplifier

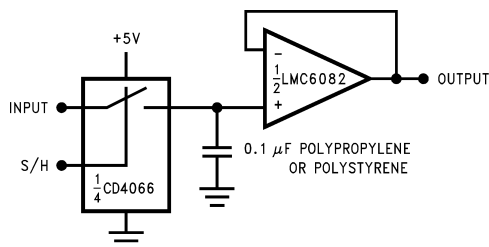


图 6-5. Low Leakage Sample and Hold

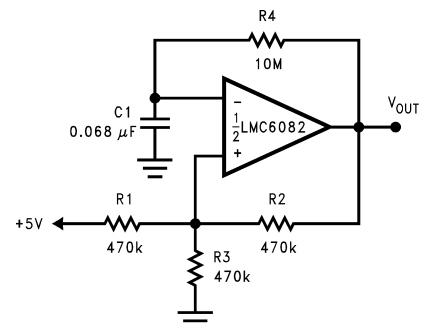


图 6-6. 1Hz Square-Wave Oscillator

6.2.2 Instrumentation Amplifier

The measurement of differential signals is quite common across many applications and are especially prevalent in biopotential sensors, for example electrocardiograms. Biopotential sensors can often be high impedance and require low input bias and current noise. Instrumentation amplifiers, introduced in the previous section, are commonly used to condition differential signals from biopotential sensors. The LMC608x are a great choice in particular due to the extremely low input bias current and current noise, high common-mode rejection ratio (CMRR) and low power. A high performance instrumentation amplifier can be achieved by using the LMC608x and a pair of RES11A matched resistors.

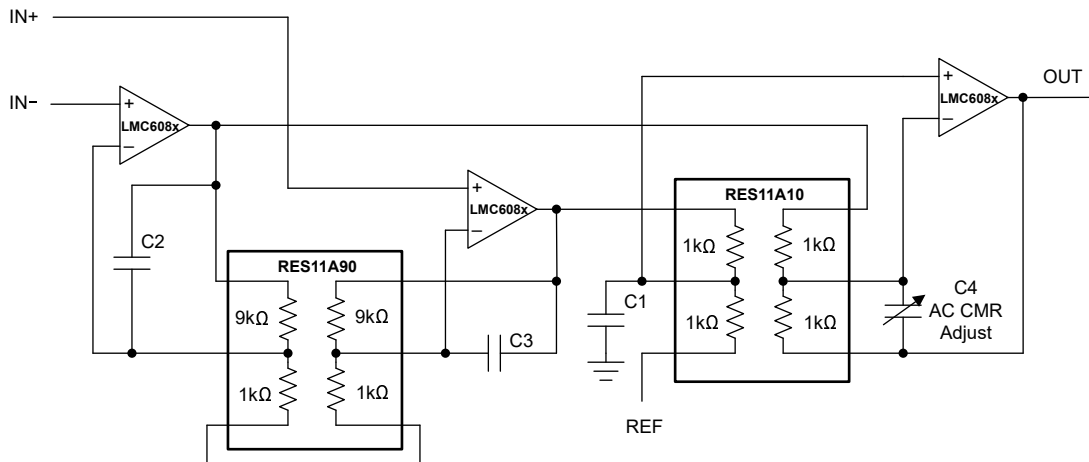


图 6-7. Instrumentation Amplifier With the RES11A

图 6-7 shows an instrumentation amplifier design with a gain of 10V/V. The first RES11A is used to set the gain of the amplifier. In this case, a ratio of 1:9 is used to create a gain of 10V/V, but many different gain configurations are possible. The second RES11A is used to build a high CMRR, low drift, unity gain difference amplifier. This design provides a precision, differential-to-single ended amplifier with very high input impedance. A smaller, lower power design, a two op amp instrumentation amplifier, is possible using the dual channel LMC6082 and only one RES11A matched pair at the expense of higher CMRR.

6.3 Layout

6.3.1 Layout Guidelines

6.3.1.1 Printed Circuit Board Layout for High-Impedance Work

Generally, any circuit that operates with less than 1000pA of leakage current requires special layout of the printed circuit board (PCB). To take advantage of the ultra-low bias current of the LMC608x, typically less than 10fA, an excellent layout is crucial. Fortunately, the techniques of obtaining low leakages are quite simple. First, do not ignore the surface leakage of the PCB, even though the leakage can sometimes appear acceptably low, because under conditions of high humidity or dust or contamination, the surface leakage can be appreciable.

To minimize the effect of any surface leakage, lay out a ring of foil completely surrounding the LMC608x inputs and the terminals of capacitors, diodes, conductors, resistors, relay terminals, and so on, connected to the op amp inputs, as in 图 6-8. To have a significant effect, place guard rings on both the top and bottom of the PCB. This PCB foil must then be connected to a voltage that is at the same voltage as the amplifier inputs because no leakage current can flow between two points at the same potential. For example, a PCB trace-to-pad resistance of $10^{12} \Omega$, which is normally considered a very large resistance, can leak 5pA if the trace were a 5V bus adjacent to the pad of the input. This leakage causes a 100 times degradation from the LMC608x actual performance. However, if a guard ring is held within 5mV of the inputs, then even a resistance of $10^{11} \Omega$ causes only 0.05pA of leakage current. See 图 6-9 to 图 6-11 for typical connections of guard rings for standard op amp configurations.

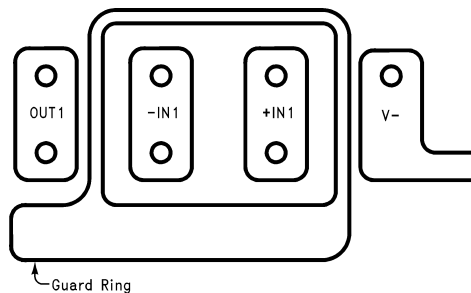


图 6-8. Example of Guard Ring in Printed Circuit Board Layout

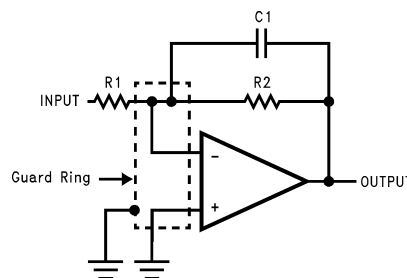


图 6-9. Typical Connections of Guard Rings: Inverting Amplifier

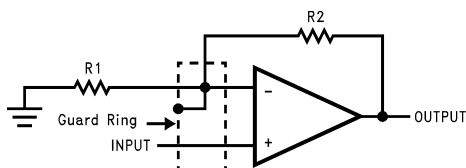


图 6-10. Typical Connections of Guard Rings:
Noninverting Amplifier

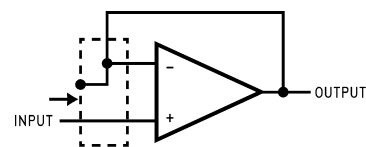
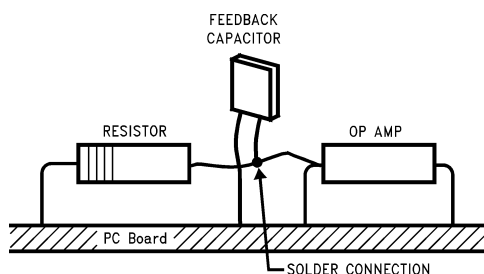


图 6-11. Typical Connections of Guard Rings:
Follower

Be aware that when laying out a PCB for the sake of just a few circuits is inappropriate, there is another technique that is even better than a guard ring on a PCB. Do not insert the amplifier input pin into the board at

all; instead, bend the pin up in the air and use only air as an insulator because air is an excellent insulator. In this case, some of the advantages of PCB construction are lost, but the advantages of air are sometimes well worth the effort of using point-to-point up-in-the-air wiring. See 图 6-12.



备注

Input pins are lifted out of PCB and soldered directly to components. All other pins are connected to PCB.

图 6-12. Air wiring

7 Device and Documentation Support

TI offers an extensive line of development tools. Tools and software to evaluate the performance of the device, generate code, and develop solutions are listed below.

7.1 接收文档更新通知

要接收文档更新通知，请导航至 ti.com 上的器件产品文件夹。点击 [通知](#) 进行注册，即可每周接收产品信息更改摘要。有关更改的详细信息，请查看任何已修订文档中包含的修订历史记录。

7.2 支持资源

[TI E2E™ 中文支持论坛](#) 是工程师的重要参考资料，可直接从专家处获得快速、经过验证的解答和设计帮助。搜索现有解答或提出自己的问题，获得所需的快速设计帮助。

链接的内容由各个贡献者“按原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的 [使用条款](#)。

7.3 Trademarks

TI E2E™ is a trademark of Texas Instruments.

所有商标均为其各自所有者的财产。

7.4 静电放电警告



静电放电 (ESD) 会损坏这个集成电路。德州仪器 (TI) 建议通过适当的预防措施处理所有集成电路。如果不遵守正确的处理和安装程序，可能会损坏集成电路。

ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

7.5 术语表

[TI 术语表](#) 本术语表列出并解释了术语、首字母缩略词和定义。

8 Revision History

注：以前版本的页码可能与当前版本的页码不同

Changes from Revision D (March 2013) to Revision E (February 2024)	Page
• 添加了 LMC6081 和 LMC6084 器件及相关内容.....	1
• 将 <i>特性</i> 中的输出摆幅负载条件从 100k Ω 更改为 2k Ω ，将单电源工作电压从 15V 更改为 15.5V 并将高压增益从 130dB 更改为 123dB，以匹配 <i>电气特性</i>	1
• 更新了 <i>说明</i> 中的器件描述.....	1
• Added <i>Pin Configurations and Functions</i>	3
• Added <i>Thermal Information</i>	6
• Changed separate DC and AC <i>Electrical Characteristics</i> into single <i>Electrical Characteristics</i>	7
• Changed parameter names to conform to latest data sheet standards in <i>Electrical Characteristics</i>	7
• Changed input current noise density specification from 0.2fA/ $\sqrt{\text{Hz}}$ to 4fA/ $\sqrt{\text{Hz}}$ in <i>Electrical Characteristics</i> ..	7
• Changed total harmonic distortion specification from 0.01% to 0.2% in <i>Electrical Characteristics</i>	7
• Added footnote detailing how slew rate minimum specification is specified in <i>Electrical Characteristics</i>	7
• Added offset voltage vs input common mode voltage and input bias vs common mode voltage curves in <i>Typical Characteristics</i>	11
• Added R_L , V_{CM} , and V_{OUT} conditions to the <i>Typical Characteristics</i> header.....	11
• Deleted Figure 4 and Figure 5 from <i>Typical Characteristics</i>	11
• Updated description in <i>Amplifier Topology</i>	15
• Added reference to RES11A instrumentation amplifier circuit in <i>Typical Single-Supply Applications</i>	17

- Added *Instrumentation Amplifier* section..... 18

Changes from Revision C (March 2013) to Revision D (March 2013)**Page**

- 添加了引脚配置和功能、规格、绝对最大额定值、ESD 等级、建议运行条件、热性能信息、电气特性、典型特性、详细说明、概述、功能方框图、特性描述、器件功能模式、应用和实施、典型应用、电源相关建议、布局、布局指南、布局示例、器件和文档支持以及机械、封装和可订购信息部分..... 1
- Changed layout of National Data Sheet to TI format..... 17

9 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package Pins	Package qty Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LMC6081-MDA	Active	Production	DIESALE (Y) 0	270 TUBE	Yes	Call TI	Level-1-NA-UNLIM	-55 to 125	
LMC6081-MDA.A	Active	Production	DIESALE (Y) 0	270 TUBE	Yes	Call TI	Level-1-NA-UNLIM	-55 to 125	
LMC6081AIM/NOPB	Obsolete	Production	SOIC (D) 8	-	-	Call TI	Call TI	-40 to 85	LMC60 81AIM
LMC6081AIMX/NOPB	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU SN	Level-1-260C-UNLIM	-40 to 85	(6081AI, LMC60) 81AIM
LMC6081AIMX/NOPB.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(6081AI, LMC60) 81AIM
LMC6081AIMX/NOPB.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(6081AI, LMC60) 81AIM
LMC6081IM/NOPB	Obsolete	Production	SOIC (D) 8	-	-	Call TI	Call TI	-40 to 85	LMC60 81IM
LMC6081IMX/NOPB	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU SN	Level-1-260C-UNLIM	-40 to 85	(6081I, LMC60) 81IM
LMC6081IMX/NOPB.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(6081I, LMC60) 81IM
LMC6081IMX/NOPB.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(6081I, LMC60) 81IM
LMC6081IN/NOPB	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6081 IN
LMC6081IN/NOPB.A	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6081 IN
LMC6081IN/NOPB.B	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6081 IN
LMC6082AIM/NOPB	Obsolete	Production	SOIC (D) 8	-	-	Call TI	Call TI	-40 to 85	LMC60 82AIM
LMC6082AIMX/NOPB	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU SN	Level-1-260C-UNLIM	-40 to 85	(6082AI, LMC60) 82AIM
LMC6082AIMX/NOPB.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(6082AI, LMC60) 82AIM
LMC6082AIMX/NOPB.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(6082AI, LMC60) 82AIM

Orderable part number	Status (1)	Material type (2)	Package Pins	Package qty Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LMC6082AIN/NOPB	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6082 AIN
LMC6082AIN/NOPB.A	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6082 AIN
LMC6082AIN/NOPB.B	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6082 AIN
LMC6082IM/NOPB	Obsolete	Production	SOIC (D) 8	-	-	Call TI	Call TI	-40 to 85	LMC60 82IM
LMC6082IMX/NOPB	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU SN	Level-1-260C-UNLIM	-40 to 85	LMC60 82IM
LMC6082IMX/NOPB.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	LMC60 82IM
LMC6082IMX/NOPB.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	LMC60 82IM
LMC6082IN/NOPB	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6082 IN
LMC6082IN/NOPB.A	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6082 IN
LMC6082IN/NOPB.B	Active	Production	PDIP (P) 8	40 TUBE	Yes	NIPDAU	Level-1-NA-UNLIM	-40 to 85	LMC6082 IN
LMC6084AIM/NOPB	Obsolete	Production	SOIC (D) 14	-	-	Call TI	Call TI	-40 to 85	LMC6084 AIM
LMC6084AIMX/NOPB	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(LMC6084, LMC6084A IM) AIM
LMC6084AIMX/NOPB.A	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	(LMC6084, LMC6084A IM) AIM
LMC6084IM/NOPB	Obsolete	Production	SOIC (D) 14	-	-	Call TI	Call TI	-40 to 85	LMC6084IM
LMC6084IMX/NOPB	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	LMC6084IM
LMC6084IMX/NOPB.A	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	LMC6084IM

⁽¹⁾ **Status:** For more details on status, see our [product life cycle](#).

(2) Material type: When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) RoHS values: Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

(4) Lead finish/Ball material: Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) MSL rating/Peak reflow: The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

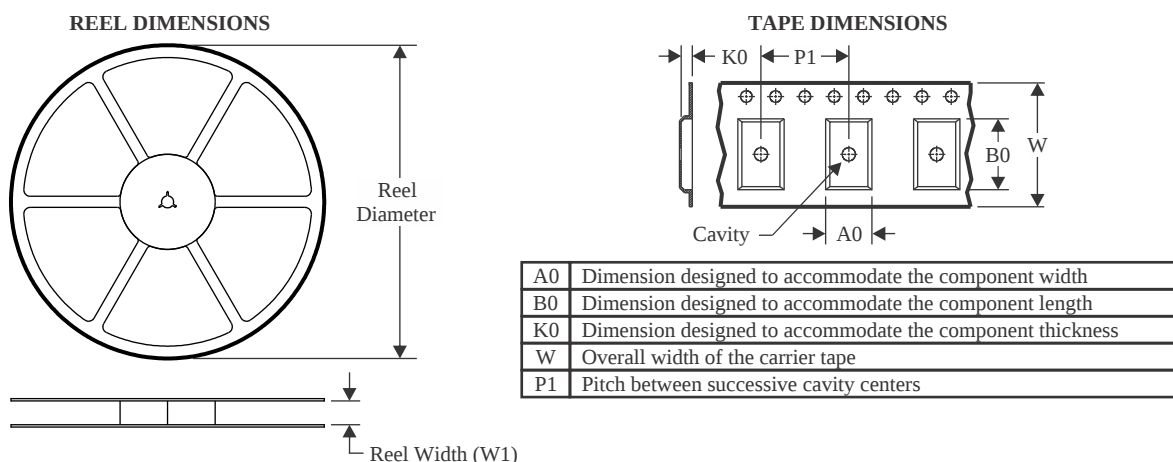
(6) Part marking: There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

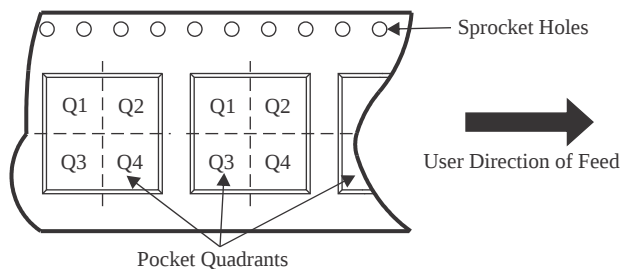
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TAPE AND REEL INFORMATION



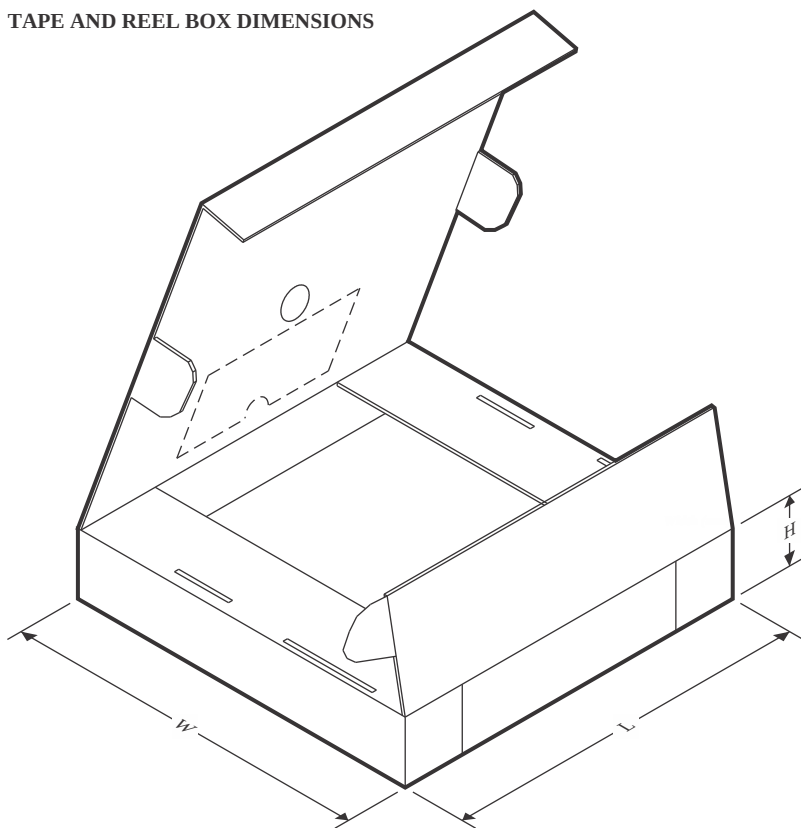
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LMC6081AIMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LMC6081AIMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LMC6081IMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LMC6081IMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LMC6082AIMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LMC6082AIMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LMC6082IMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LMC6082IMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
LMC6084AIMX/NOPB	SOIC	D	14	2500	330.0	16.4	6.5	9.0	2.1	8.0	16.0	Q1
LMC6084IMX/NOPB	SOIC	D	14	2500	330.0	16.4	6.5	9.0	2.1	8.0	16.0	Q1

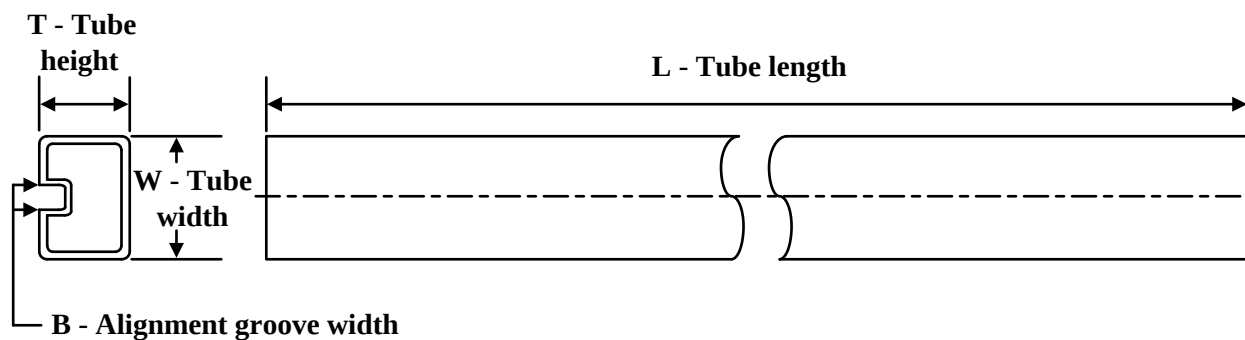
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

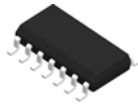
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LMC6081AIMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LMC6081AIMX/NOPB	SOIC	D	8	2500	353.0	353.0	32.0
LMC6081IMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LMC6081IMX/NOPB	SOIC	D	8	2500	353.0	353.0	32.0
LMC6082AIMX/NOPB	SOIC	D	8	2500	353.0	353.0	32.0
LMC6082AIMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LMC6082IMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LMC6082IMX/NOPB	SOIC	D	8	2500	353.0	353.0	32.0
LMC6084AIMX/NOPB	SOIC	D	14	2500	353.0	353.0	32.0
LMC6084IMX/NOPB	SOIC	D	14	2500	353.0	353.0	32.0

TUBE

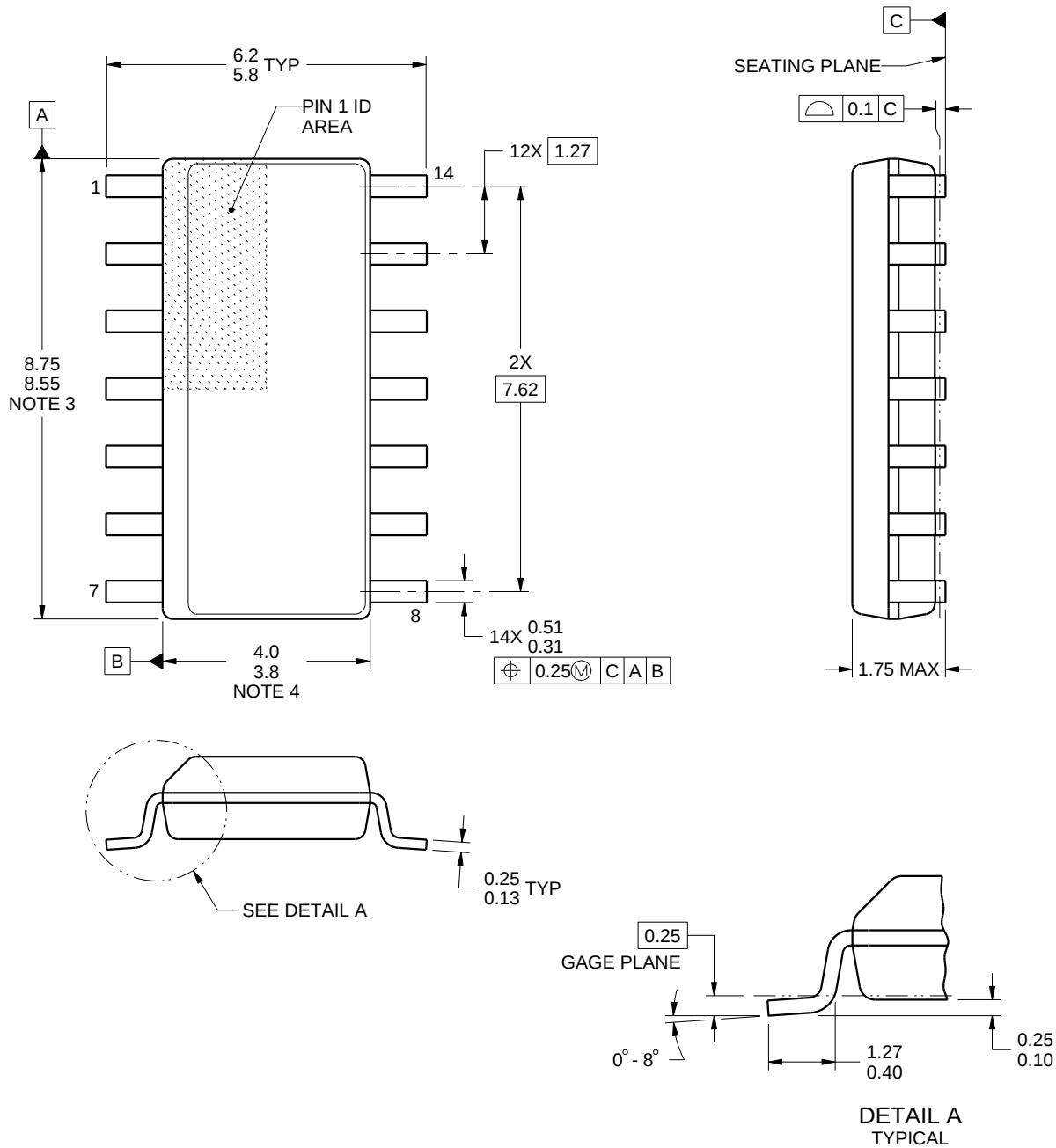


*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (μm)	B (mm)
LMC6081IN/NOPB	P	PDIP	8	40	502	14	11938	4.32
LMC6081IN/NOPB.A	P	PDIP	8	40	502	14	11938	4.32
LMC6081IN/NOPB.B	P	PDIP	8	40	502	14	11938	4.32
LMC6082AIN/NOPB	P	PDIP	8	40	502	14	11938	4.32
LMC6082AIN/NOPB.A	P	PDIP	8	40	502	14	11938	4.32
LMC6082AIN/NOPB.B	P	PDIP	8	40	502	14	11938	4.32
LMC6082IN/NOPB	P	PDIP	8	40	502	14	11938	4.32
LMC6082IN/NOPB.A	P	PDIP	8	40	502	14	11938	4.32
LMC6082IN/NOPB.B	P	PDIP	8	40	502	14	11938	4.32

D0014A**PACKAGE OUTLINE****SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



4220718/A 09/2016

NOTES:

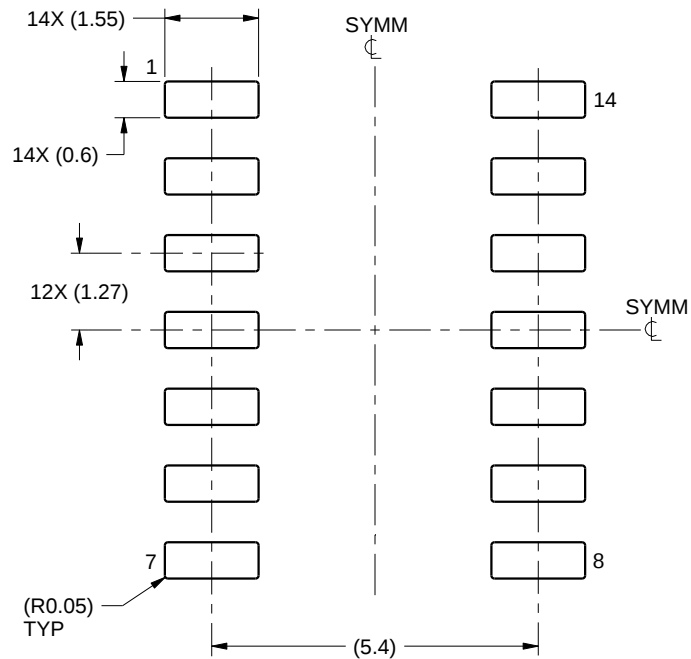
1. All linear dimensions are in millimeters. Dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm, per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.43 mm, per side.
5. Reference JEDEC registration MS-012, variation AB.

EXAMPLE BOARD LAYOUT

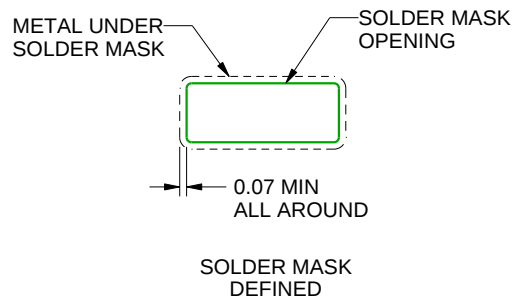
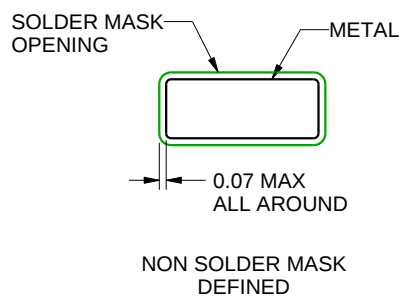
D0014A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE
SCALE:8X



SOLDER MASK DETAILS

4220718/A 09/2016

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

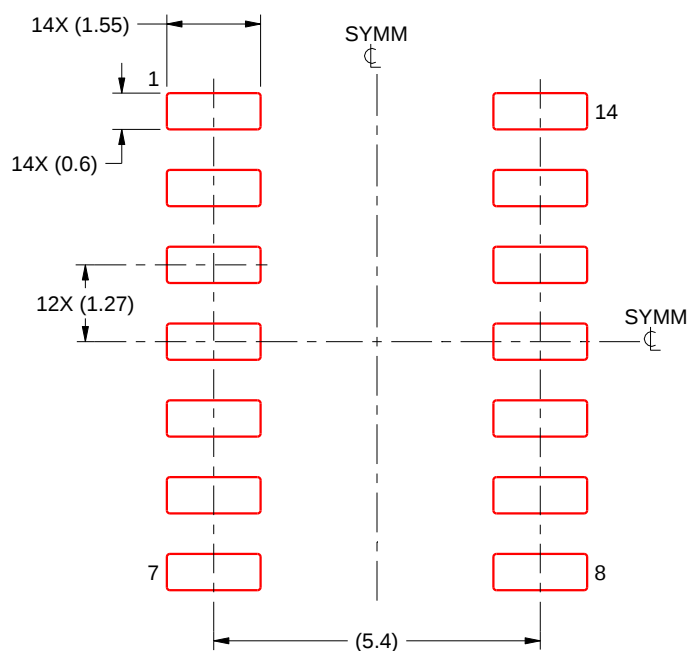
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0014A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:8X

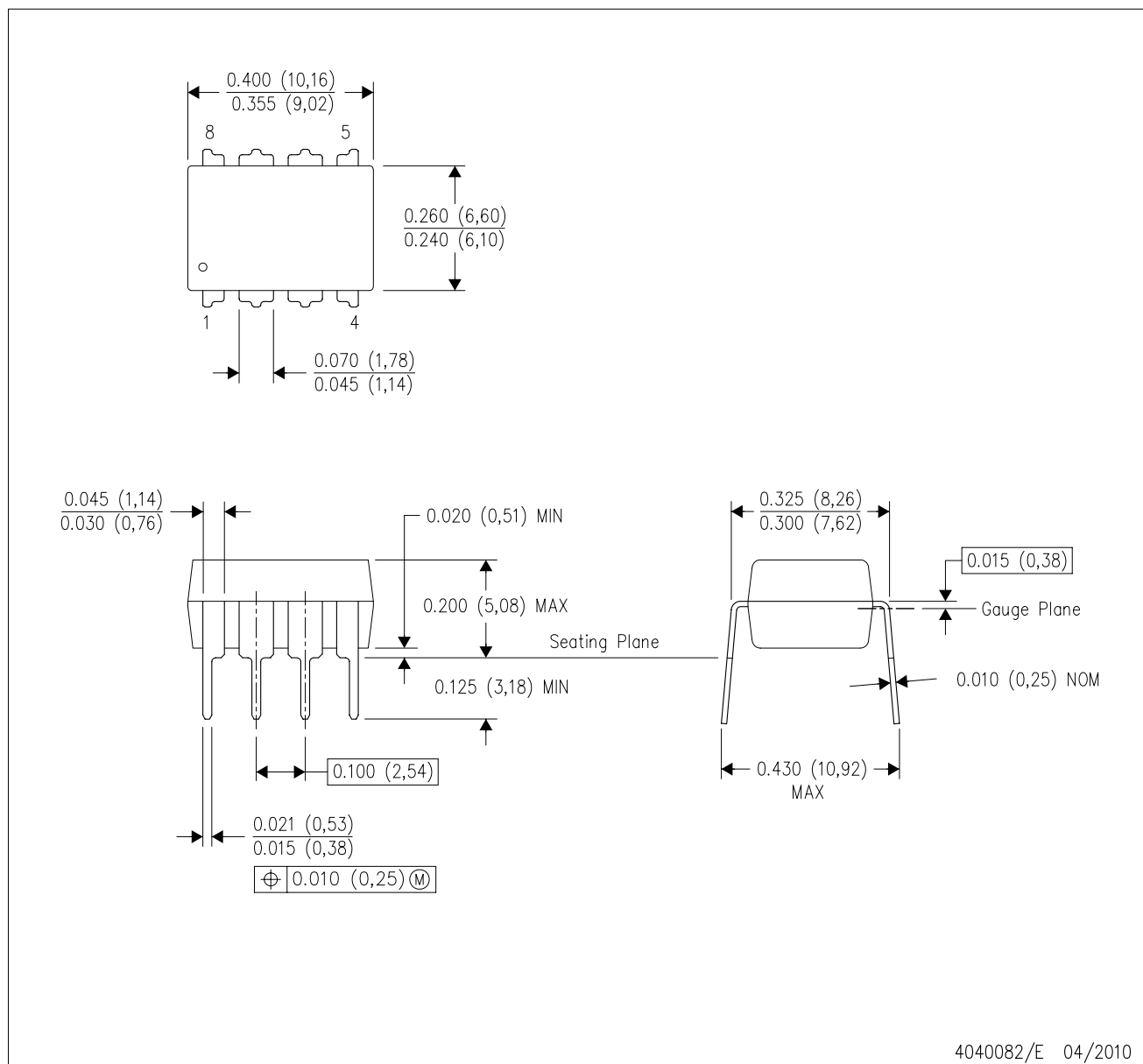
4220718/A 09/2016

NOTES: (continued)

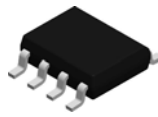
8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

P (R-PDIP-T8)

PLASTIC DUAL-IN-LINE PACKAGE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - C. Falls within JEDEC MS-001 variation BA.

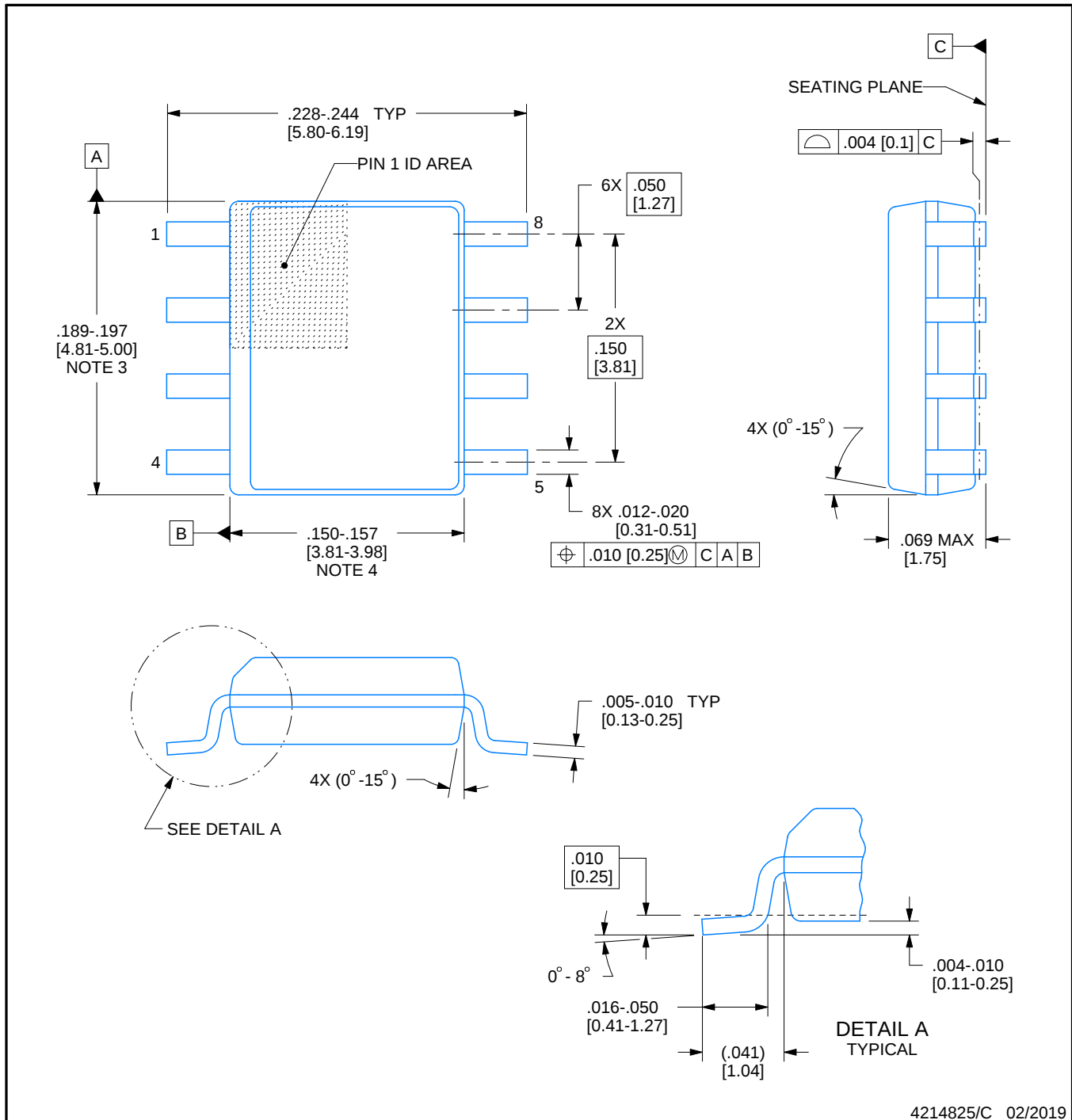


D0008A

PACKAGE OUTLINE

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

NOTES:

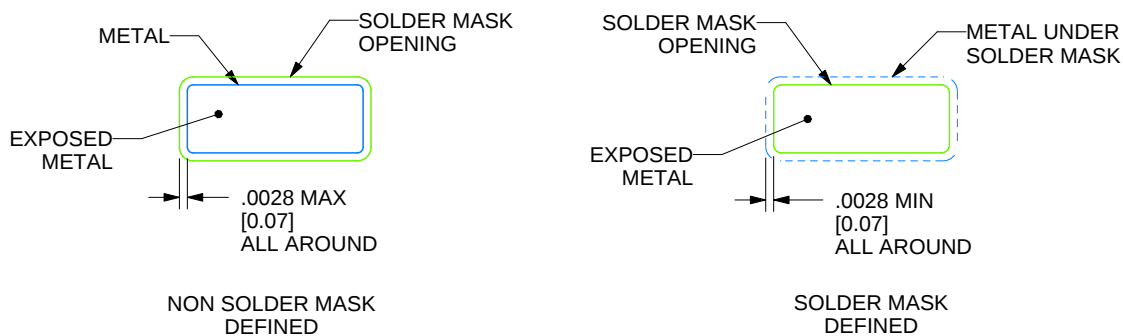
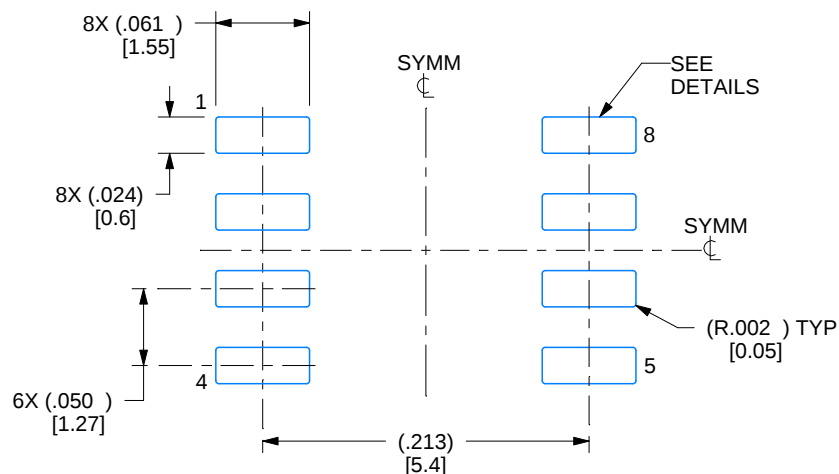
1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.

EXAMPLE BOARD LAYOUT

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

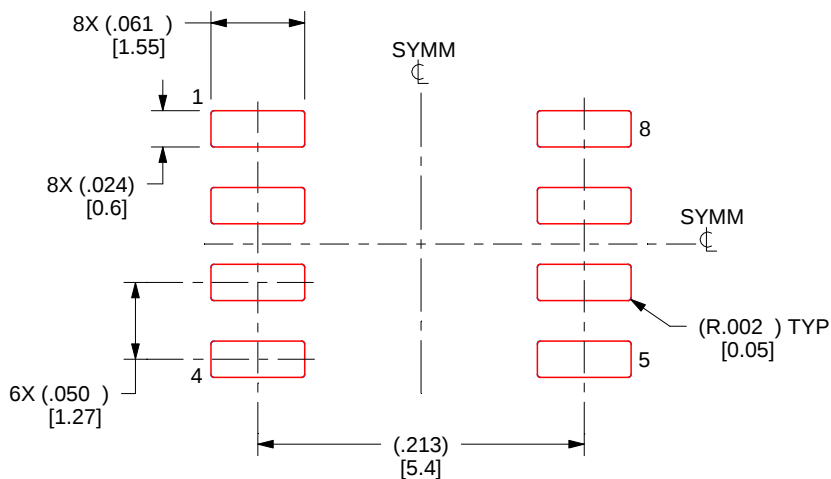
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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最后更新日期：2025 年 10 月