

TLC227x-Q1 高级轨到轨 LinCMOS™ 运算放大器

1 特性

- 符合面向汽车应用的 AEC-Q100 标准
 - 温度等级 1：-40 °C 至 125 °C、 T_A
- 提供功能安全
 - 可提供用于功能安全系统设计的文档 (TLC2272-Q1)
 - 可提供用于功能安全系统设计的文档 (TLC2272A-Q1)
- 输出摆幅包括两个电源轨
- 低噪声：在 $f = 1\text{kHz}$ 时为 $9\text{nV}/\sqrt{\text{Hz}}$ (典型值)
- 低输入偏置电流：1pA (典型值)
- 完全符合单电源及双电源供电的要求
- 共模输入电压范围包括负轨
- 高增益带宽：2.2MHz (典型值)
- 高压摆率：3.6V/ μs (典型值)
- 低输入失调电压： $T_A = 25^\circ\text{C}$ 时最大值为 $950\mu\text{V}$
- 包括宏模型

2 应用

- 车身控制模块
- 电池管理系统
- 车载音频
- 直流/直流转换器
- 电动动力转向
- 引擎控制单元
- 汽油引擎
- 仪表组
- 逆变器和电机控制
- 车载充电器
- 远程信息处理控制单元
- 变速器控制
- 白色家电 (冰箱、洗衣机)

3 说明

TLC227x-Q1 为双通道和四通道 LinCMOS™ 运算放大器。两款器件均在单电源或双电源应用中表现出优异的轨到轨输出性能，能够进一步扩大动态范围。TLC227x-Q1 系列器件可为更高速率的应用提供 2MHz 的带宽和 3V/ μs 的压摆率。这些器件能够提供出色的交流性能，其噪声、输入失调电压和功耗均低于现有 CMOS 运算放大器。TLC227x-Q1 的噪声电压为 $9\text{nV}/\sqrt{\text{Hz}}$ ，是同类解决方案的二分之一。

TLC227x-Q1 具有高输入阻抗和低噪声特性，是用于高阻抗源 (如压电式传感器) 小信号调节的理想选择。此外，该系列器件的单电源或双电源具有轨到轨输出特性，是与模数转换器 (ADC) 连接的理想选择。

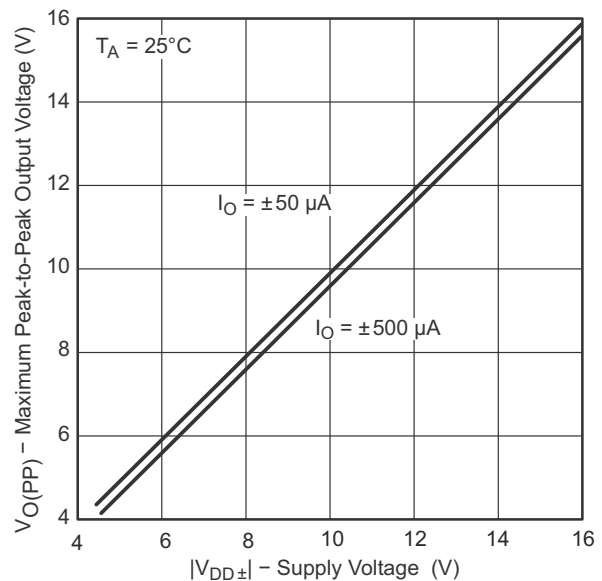
对于精密应用，TLC227xA-Q1 系列器件的最大输入失调电压为 $950\mu\text{V}$ 。该器件系列的额定工作电压为 5V 或 $\pm 5\text{V}$ 。

这些器件可提供更大的输出动态范围，更低的噪声电压和输入失调电压。凭借这一系列增强特性，TLC227x-Q1 能够用于更广泛的应用。对于需要更高输出驱动和更宽输入电压范围的应用，请参阅 TLV2432-Q1 和 TLV2442-Q1。TLC227x-Q1 系列器件的所有参数使这些器件能够适用于大多数汽车应用。

封装信息

器件型号	封装 ⁽¹⁾	封装尺寸 (标称值)
TLC2272-Q1、 TLC2272A-Q1	SOIC (8)	4.90mm × 3.91mm
	TSSOP (8)	3.00mm × 4.40mm
TLC2274-Q1、 TLC2274A-Q1	SOIC (14)	8.65mm × 3.91mm
	TSSOP (14)	5.00mm × 4.40mm

(1) 如需了解所有可用封装，请参阅数据表末尾的可订购产品附录。



最大峰-峰值输出电压与电源电压



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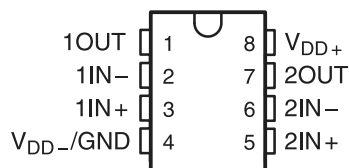
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4 Revision History

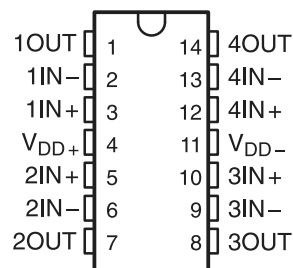
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Changes from Revision F (March 2016) to Revision G (August 2022)	Page
• 更新了整个文档中的表格、图和交叉参考的编号格式.....	1
• 向特性要点添加了功能安全信息.....	1
Changes from Revision E (January 2012) to Revision F (March 2016)	Page
• 添加了引脚配置和功能部分、特性说明部分、器件功能模式、应用和实施部分、电源相关建议部分、布局部分、器件和文档支持部分以及机械、封装和可订购信息部分.....	1
• Added ESD ratings table.....	4
Changes from Revision D (March 2009) to Revision E (January 2012)	Page
• Deleted ESD ratings table.....	4

5 Pin Configuration and Functions



**图 5-1. TLC2272-Q1 and TLC2272A-Q1:
D (8-Pin SOIC) or PW (8-Pin TSSOP)
Packages, Top View**



**图 5-2. TLC2274-Q1 and TLC2274A-Q1:
D (14-Pin SOIC) or PW (14-Pin TSSOP)
Packages, Top View**

表 5-1. Pin Functions

NAME	PIN NO.		TYPE	DESCRIPTION
	TLC2272-Q1, TLC2272A-Q1	TLC2274-Q1, TLC2274A-Q1		
1IN+	3	3	Input	Noninverting input, channel 1
1IN -	2	2	Input	Inverting input, channel 1
1OUT	1	1	Output	Output, channel 1
2IN+	5	5	Input	Noninverting input, channel 2
2IN -	6	6	Input	Inverting input, channel 2
2OUT	7	7	Ouput	Output, channel 2
3IN+	—	10	Input	Noninverting input, channel 3
3IN -	—	9	Input	Inverting input, channel 3
3OUT	—	8	Output	Output, channel 3
4IN+	—	12	Input	Noninverting input, channel 4
4IN -	—	13	Input	Inverting input, channel 4
4OUT	—	14	Output	Output, channel 4
V _{DD+}	8	4	Input	Positive (highest) supply
V _{DD-}	4	11	Input	Negative (lowest) supply

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)⁽¹⁾

	MIN	MAX	UNIT
Supply voltage, V_{DD+} ⁽²⁾		8	V
V_{DD-} ⁽²⁾	- 8		V
Differential input voltage, V_{ID} ⁽³⁾		±16	V
Input voltage, V_I (any input) ⁽²⁾	$V_{DD-} - 0.3$	V_{DD+}	V
Input current, I_I (any input)		±5	mA
Output current, I_O		±50	mA
Total current into V_{DD+}		±50	mA
Total current out of V_{DD-}		±50	mA
Duration of short-circuit current at (or below) 25°C ⁽⁴⁾		Unlimited	
Operating free-air temperature range, T_A	- 40	125	°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	D or PW package		260
Storage temperature, T_{stg}	- 65	150	°C

- (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 [§ 6.3](#). Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) All voltage values, except differential voltages, are with respect to the midpoint between V_{DD+} and V_{DD-} .
- (3) Differential voltages are at $IN+$ with respect to $IN-$. Excessive current will flow if input is brought below $V_{DD-} - 0.3$ V.
- (4) The output can be shorted to either supply. Temperature or supply voltages must be limited so that the maximum dissipation rating is not exceeded.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per AEC Q100-002 ⁽¹⁾ HBM ESD classification level 2	±2000	V
		Charged-device model (CDM), per AEC Q100-011 CDM ESD classification level C6	±1000	

- (1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.3 Recommended Operating Conditions

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

		MIN	MAX	UNIT
$V_{DD±}$	Supply voltage	±2.2	±8	V
V_I	Input voltage	V_{DD-}	$V_{DD+} - 1.5$	V
V_{IC}	Common-mode input voltage	V_{DD-}	$V_{DD+} - 1.5$	V
T_A	Operating free-air temperature	-40	125	°C

6.4 Thermal Information

THERMAL METRIC ⁽¹⁾		TLC2272-Q1, TLC2272A-Q1		TLC2274-Q1, TLC2274A-Q1		UNIT
		D (SOIC)	PW (TSSOP)	D (SOIC)	PW (TSSOP)	
		8 PINS	8 PINS	14 PINS	14 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	115.6	175.8	83.8	111.6	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	61.8	58.8	43.2	41.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	55.9	104.3	38.4	54.7	°C/W
ψ_{JT}	Junction-to-top characterization parameter	14.3	5.9	9.4	3.9	°C/W
ψ_{JB}	Junction-to-board characterization parameter	55.4	102.3	38.1	53.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	—	—	—	—	°C/W

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

6.5 Electrical Characteristics: $V_{DD} = 5\text{ V}$ (TLC2272-Q1 and TLC2272A-Q1)

at specified free-air temperature, $V_{DD} = 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$	TLC2272-Q1 $T_A = 25^\circ\text{C}$		300	2500	μV
			TLC2272A-Q1		300	950	
			TLC2272-Q1 Full Range ⁽¹⁾			3000	
			TLC2272A-Q1			1500	
α_{VIO}	Temperature coefficient of input offset voltage	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$			2		$\mu\text{V}/^\circ\text{C}$
	Input offset voltage long-term drift ⁽²⁾	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$			0.002		$\mu\text{V}/\text{mo}$
I_{IO}	Input offset current	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$		0.5	60	pA
			Full Range ⁽¹⁾			800	
I_{IB}	Input bias current	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$		1	60	pA
			Full Range ⁽¹⁾			800	
V_{ICR}	Common-mode input voltage	$R_S = 50\ \Omega$; $ V_{IO} \leq 5\text{ mV}$	$T_A = 25^\circ\text{C}$	-0.3	2.5	4	V
			Full Range ⁽¹⁾	0	2.5	3.5	
V_{OH}	High-level output voltage	$I_{OH} = -20\ \mu\text{A}$ $I_{OH} = -200\ \mu\text{A}$ $I_{OH} = -1\text{ mA}$	$T_A = 25^\circ\text{C}$		4.99		V
			Full Range ⁽¹⁾		4.85	4.93	
			$T_A = 25^\circ\text{C}$		4.25	4.65	
			Full Range ⁽¹⁾		4.25		
V_{OL}	Low-level output voltage	$V_{IC} = 2.5\text{ V}$	$I_{OL} = 50\ \mu\text{A}$ $T_A = 25^\circ\text{C}$		0.01		V
			$I_{OL} = 500\ \mu\text{A}$		0.09	0.15	
			Full Range ⁽¹⁾			0.15	
			$I_{OL} = 5\text{ mA}$ $T_A = 25^\circ\text{C}$		0.9	1.5	
A_{VD}	Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$, $V_O = 1\text{ V to }4\text{ V}$	$R_L = 10\text{ k}\Omega$ ⁽³⁾ $T_A = 25^\circ\text{C}$	10	35		V/mV
			Full Range ⁽¹⁾	10			
			$R_L = 1\text{ M}\Omega$ ⁽³⁾		175		
r_{id}	Differential input resistance				10^{12}		Ω
r_i	Common-mode input resistance				10^{12}		Ω
c_i	Common-mode input capacitance	$f = 10\text{ kHz}$, P package			8		pF
z_o	Closed-loop output impedance	$f = 1\text{ MHz}$, $A_V = 10$			140		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = 0\text{ V to }2.7\text{ V}$, $V_O = 2.5\text{ V}$, $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$	70	75		dB
			Full Range ⁽¹⁾	70			
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 4.4\text{ V to }16\text{ V}$, $V_{IC} = V_{DD} / 2$, no load	$T_A = 25^\circ\text{C}$	80	95		dB
			Full Range ⁽¹⁾	80			

6.5 Electrical Characteristics: $V_{DD} = 5\text{ V}$ (TLC2272-Q1 and TLC2272A-Q1) (continued)

at specified free-air temperature, $V_{DD} = 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
I_{DD}	Supply current	$V_O = 2.5\text{ V}$, no load	$T_A = 25^\circ\text{C}$		2.2	3	mA
			Full Range ⁽¹⁾			3	
SR	Slew rate at unity gain	$V_O = 0.5\text{ V}$ to 2.5 V , $R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾	$T_A = 25^\circ\text{C}$	2.3	3.6		V/ μs
			Full Range ⁽¹⁾	1.7			
V_n	Equivalent input noise voltage	$f = 10\text{ Hz}$			50		nV/ $\sqrt{\text{Hz}}$
		$f = 1\text{ kHz}$			9		
V_{NPP}	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz}$ to 1 Hz			1		μV
		$f = 0.1\text{ Hz}$ to 10 Hz			1.4		
I_n	Equivalent input noise current				0.6		fA/ $\sqrt{\text{Hz}}$
THD+N	Total harmonic distortion + noise	$V_O = 0.5\text{ V}$ to 2.5 V , $f = 20\text{ kHz}$, $R_L = 10\text{ k}\Omega$ ⁽³⁾	$A_V = 1$		0.0013%		
			$A_V = 10$		0.004%		
			$A_V = 100$		0.03%		
	Gain-bandwidth product	$f = 10\text{ kHz}$, $R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾			2.18		MHz
B_{OM}	Maximum output-swing bandwidth	$V_{O(PP)} = 2\text{ V}$, $A_V = 1$, $R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾			1		MHz
t_s	Settling time	$A_V = -1$, $R_L = 10\text{ k}\Omega$ ⁽³⁾ , Step = 0.5 V to 2.5 V , $C_L = 100\text{ pF}$ ⁽³⁾	To 0.1%		1.5		μs
			To 0.01%		2.6		
ϕ_m	Phase margin at unity gain	$R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾			50°		
	Gain margin	$R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾			10		dB

(1) $T_A = -40^\circ\text{C}$ to 125°C .

(2) Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A = 150^\circ\text{C}$ extrapolated to $T_A = 25^\circ\text{C}$ using the Arrhenius equation and assuming an activation energy of 0.96 eV.

(3) Referenced to 0 V.

6.6 Electrical Characteristics: $V_{DD\pm} = \pm 5\text{ V}$ (TLC2272-Q1 and TLC2272A-Q1)

at specified free-air temperature, $V_{DD\pm} = \pm 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage	$V_{IC} = 0\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\text{ }\Omega$	TLC2272-Q1	$T_A = 25^\circ\text{C}$	300	2500	μV
			TLC2272A-Q1		300	950	
			TLC2272-Q1	Full Range ⁽¹⁾		3000	
			TLC2272A-Q1			1500	
α_{VIO}	Temperature coefficient of input offset voltage	$V_{IC} = 0\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\text{ }\Omega$			2		$\mu\text{ V}/^\circ\text{C}$
	Input offset voltage long-term drift ⁽²⁾	$V_{IC} = 0\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\text{ }\Omega$			0.002		$\mu\text{ V}/\text{mo}$
I_{IO}	Input offset current	$V_{IC} = 0\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\text{ }\Omega$	$T_A = 25^\circ\text{C}$		0.5	60	pA
			Full Range ⁽¹⁾			800	
I_{IB}	Input bias current	$V_{IC} = 0\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\text{ }\Omega$	$T_A = 25^\circ\text{C}$		1	60	pA
			Full Range ⁽¹⁾			800	
V_{ICR}	Common-mode input voltage	$R_S = 50\text{ }\Omega$; $ V_{IO} \leq 5\text{ mV}$	$T_A = 25^\circ\text{C}$	-5.3	0	4	V
			Full Range ⁽¹⁾	-5	0	3.5	
V_{OM+}	Maximum positive peak output voltage	$I_O = -20\text{ }\mu\text{A}$			4.99		V
			$T_A = 25^\circ\text{C}$	4.85	4.93		
		$I_O = -200\text{ }\mu\text{A}$	Full Range ⁽¹⁾	4.85			
			$T_A = 25^\circ\text{C}$	4.25	4.65		
		$I_O = -1\text{ mA}$	Full Range ⁽¹⁾	4.25			

6.6 Electrical Characteristics: $V_{DD\pm} = \pm 5\text{ V}$ (TLC2272-Q1 and TLC2272A-Q1) (continued)

at specified free-air temperature, $V_{DD\pm} = \pm 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER		TEST CONDITIONS			MIN	TYP	MAX	UNIT
V _{OM-}	Maximum negative peak output voltage	V _{IC} = 0 V	I _O = 50 μA		- 4.99		V	
			I _O = 500 μA	T _A = 25°C	- 4.85	- 4.91		
				Full Range ⁽¹⁾	- 4.85			
			I _O = 5 mA	T _A = 25°C	- 3.5	- 4.1		
Full Range ⁽¹⁾	- 3.5							
A _{VD}	Large-signal differential voltage amplification	V _O = ±4 V	R _L = 10 kΩ	T _A = 25°C	20	50	V/mV	
				Full Range ⁽¹⁾	20			
			R _L = 1 MΩ		300			
r _{id}	Differential input resistance					10 ¹²	Ω	
r _i	Common-mode input resistance					10 ¹²	Ω	
c _i	Common-mode input capacitance	f = 10 kHz, P package				8	pF	
Z _O	Closed-loop output impedance	f = 1 MHz, A _V = 10				130	Ω	
CMRR	Common-mode rejection ratio	V _{IC} = - 5 V to 2.7 V, V _O = 0 V, R _S = 50 Ω	T _A = 25°C		75	80	dB	
			Full Range ⁽¹⁾		75			
k _{SVR}	Supply-voltage rejection ratio (Δ V _{DD} / Δ V _{IO})	V _{DD+} = 2.2 V to ±8 V, V _{IC} = 0 V, no load	T _A = 25°C		80	95	dB	
			Full Range ⁽¹⁾		80			
I _{DD}	Supply current	V _O = 0 V, no load	T _A = 25°C		2.4	3	mA	
			Full Range ⁽¹⁾			3		
SR	Slew rate at unity gain	V _O = ±2.3 V, R _L = 10 kΩ , C _L = 100 pF	T _A = 25°C		2.3	3.6	V/μs	
			Full Range ⁽¹⁾		1.7			
V _n	Equivalent input noise voltage	f = 10 Hz			50		nV/ √ Hz	
		f = 1 kHz			9			
V _{NPP}	Peak-to-peak equivalent input noise voltage	f = 0.1 Hz to 1 Hz			1		μV	
		f = 0.1 Hz to 10 Hz			1.4			
I _n	Equivalent input noise current					0.6	fA/ √ Hz	
THD+N	Total harmonic distortion + noise	V _O = ±2.3, f = 20 kHz, R _L = 10 kΩ	A _V = 1		0.0011%			
			A _V = 10		0.004%			
			A _V = 100		0.03%			
	Gain-bandwidth product	f = 10 kHz, R _L = 10 kΩ , C _L = 100 pF			2.25		MHz	
B _{OM}	Maximum output-swing bandwidth	V _{O(PP)} = 4.6 V, A _V = 1, R _L = 10 kΩ , C _L = 100 pF				0.54	MHz	
t _s	Settling time	A _V = - 1, R _L = 10 kΩ , Step = - 2.3 V to 2.3 V, C _L = 100 pF	To 0.1%		1.5		μs	
			To 0.01%		3.2			
φ _m	Phase margin at unity gain	R _L = 10 kΩ , C _L = 100 pF			52°			
	Gain margin	R _L = 10 kΩ , C _L = 100 pF			10		dB	

(1) $T_A = -40^\circ\text{C to } 125^\circ\text{C}$.

(2) Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A = 150^\circ\text{C}$ extrapolated to $T_A = 25^\circ\text{C}$ using the Arrhenius equation and assuming an activation energy of 0.96 eV.

6.7 Electrical Characteristics: $V_{DD} = 5\text{ V}$ (TLC2274-Q1 and TLC2274A-Q1)

at specified free-air temperature, $V_{DD} = 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$	TLC2274-Q1	$T_A = 25^\circ\text{C}$	300	2500	μV
			TLC2274A-Q1		300	950	
			TLC2274-Q1	Full Range ⁽¹⁾		3000	
			TLC2274A-Q1			1500	
α_{VIO}	Temperature coefficient of input offset voltage	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$			2		$\mu\text{V}/^\circ\text{C}$
	Input offset voltage long-term drift ⁽²⁾	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$			0.002		$\mu\text{V}/\text{mo}$
I_{IO}	Input offset current	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$	0.5	60		pA
			Full Range ⁽¹⁾		800		
I_{IB}	Input bias current	$V_{IC} = 0\text{ V}$, $V_{DD\pm} = \pm 2.5\text{ V}$, $V_O = 0\text{ V}$, $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$	1	60		pA
			Full Range ⁽¹⁾		800		
V_{ICR}	Common-mode input voltage	$R_S = 50\ \Omega$; $ V_{IO} \leq 5\text{ mV}$	$T_A = 25^\circ\text{C}$	-0.3	2.5	4	V
			Full Range ⁽¹⁾	0	2.5	3.5	
V_{OH}	High-level output voltage	$I_{OH} = -20\ \mu\text{A}$ $I_{OH} = -200\ \mu\text{A}$ $I_{OH} = -1\text{ mA}$	$T_A = 25^\circ\text{C}$	4.85	4.93		V
			Full Range ⁽¹⁾	4.85			
			$T_A = 25^\circ\text{C}$	4.25	4.65		
			Full Range ⁽¹⁾	4.25			
V_{OL}	Low-level output voltage	$V_{IC} = 2.5\text{ V}$	$I_{OL} = 50\ \mu\text{A}$		0.01		V
			$I_{OL} = 500\ \mu\text{A}$	$T_A = 25^\circ\text{C}$	0.09	0.15	
				Full Range ⁽¹⁾		0.15	
			$I_{OL} = 5\text{ mA}$	$T_A = 25^\circ\text{C}$	0.9	1.5	
A_{VD}	Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$, $V_O = 1\text{ V to }4\text{ V}$	$R_L = 10\text{ k}\Omega$ ⁽³⁾	$T_A = 25^\circ\text{C}$	10	35	V/mV
				Full Range ⁽¹⁾	10		
			$R_L = 1\text{ M}\Omega$ ⁽³⁾		175		
r_{id}	Differential input resistance				10^{12}		Ω
r_i	Common-mode input resistance				10^{12}		Ω
c_i	Common-mode input capacitance	$f = 10\text{ kHz}$, P package			8		pF
z_o	Closed-loop output impedance	$f = 1\text{ MHz}$, $A_V = 10$			140		Ω
CMRR	Common-mode rejection ratio	$V_{IC} = 0\text{ V to }2.7\text{ V}$, $V_O = 2.5\text{ V}$, $R_S = 50\ \Omega$	$T_A = 25^\circ\text{C}$	70	75		dB
			Full Range ⁽¹⁾	70			
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 4.4\text{ V to }16\text{ V}$, $V_{IC} = V_{DD} / 2$, no load	$T_A = 25^\circ\text{C}$	80	95		dB
			Full Range ⁽¹⁾	80			
I_{DD}	Supply current	$V_O = 2.5\text{ V}$, no load	$T_A = 25^\circ\text{C}$	4.4	6		mA
			Full Range ⁽¹⁾		6		
SR	Slew rate at unity gain	$V_O = 0.5\text{ V to }2.5\text{ V}$, $R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾	$T_A = 25^\circ\text{C}$	2.3	3.6		$\text{V}/\mu\text{s}$
			Full Range ⁽¹⁾	1.7			
V_n	Equivalent input noise voltage	$f = 10\text{ Hz}$		50			$\text{nV}/\sqrt{\text{Hz}}$
		$f = 1\text{ kHz}$		9			
V_{NPP}	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz to }1\text{ Hz}$		1			μV
		$f = 0.1\text{ Hz to }10\text{ Hz}$		1.4			
I_n	Equivalent input noise current			0.6			$\text{fA}/\sqrt{\text{Hz}}$
THD+N	Total harmonic distortion + noise	$V_O = 0.5\text{ V to }2.5\text{ V}$, $f = 20\text{ kHz}$, $R_L = 10\text{ k}\Omega$ ⁽³⁾	$A_V = 1$	0.0013%			
			$A_V = 10$	0.004%			
			$A_V = 100$	0.03%			
	Gain-bandwidth product	$f = 10\text{ kHz}$, $R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾		2.18			MHz
B_{OM}	Maximum output-swing bandwidth	$V_{O(PP)} = 2\text{ V}$, $A_V = 1$, $R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾		1			MHz

6.7 Electrical Characteristics: $V_{DD} = 5\text{ V}$ (TLC2274-Q1 and TLC2274A-Q1) (continued)

at specified free-air temperature, $V_{DD} = 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_s	Settling time	$A_V = -1$, $R_L = 10\text{ k}\Omega$ ⁽³⁾ , Step = 0.5 V to 2.5 V, $C_L = 100\text{ pF}$ ⁽³⁾	To 0.1% To 0.01%	1.5 2.6	μs
ϕ_m	Phase margin at unity gain	$R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾	50°		
	Gain margin	$R_L = 10\text{ k}\Omega$ ⁽³⁾ , $C_L = 100\text{ pF}$ ⁽³⁾	10		dB

- (1) $T_A = -40^\circ\text{C}$ to 125°C .
- (2) Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A = 150^\circ\text{C}$ extrapolated to $T_A = 25^\circ\text{C}$ using the Arrhenius equation and assuming an activation energy of 0.96 eV.
- (3) Referenced to 0 V.

6.8 Electrical Characteristics: $V_{DD\pm} = \pm 5\text{ V}$ (TLC2274-Q1 and TLC2274A-Q1)

at specified free-air temperature, $V_{DD\pm} = \pm 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER		TEST CONDITIONS			MIN	TYP	MAX	UNIT	
V _{IO}	Input offset voltage	V _{IC} = 0 V, V _O = 0 V, R _S = 50 Ω	TLC2274-Q1	T _A = 25°C		300	2500	μV	
			TLC2274A-Q1			300	950		
			TLC2274-Q1	Full Range ⁽¹⁾			3000		
			TLC2274A-Q1				1500		
α V _{IO}	Temperature coefficient of input offset voltage	V _{IC} = 0 V, V _O = 0 V, R _S = 50 Ω				2		μ V/°C	
	Input offset voltage long-term drift ⁽²⁾	V _{IC} = 0 V, V _O = 0 V, R _S = 50 Ω				0.002		μ V/mo	
I _{IO}	Input offset current	V _{IC} = 0 V, V _O = 0 V, R _S = 50 Ω	T _A = 25°C			0.5	60	pA	
			Full Range ⁽¹⁾				800		
I _{IB}	Input bias current	V _{IC} = 0 V, V _O = 0 V, R _S = 50 Ω	T _A = 25°C			1	60	pA	
			Full Range ⁽¹⁾				800		
V _{ICR}	Common-mode input voltage	R _S = 50 Ω ; V _{IO} ≤ 5 mV	T _A = 25°C		- 5.3	0	4	V	
			Full Range ⁽¹⁾		- 5	0	3.5		
V _{OM+}	Maximum positive peak output voltage	I _O = -20 μA				4.99		V	
		I _O = -200 μA	T _A = 25°C		4.85	4.93			
			Full Range ⁽¹⁾			4.85			
		I _O = -1 mA	T _A = 25°C		4.25	4.65			
Full Range ⁽¹⁾				4.25					
V _{OM-}	Maximum negative peak output voltage	V _{IC} = 0 V	I _O = 50 μA			- 4.99		V	
			I _O = 500 μA	T _A = 25°C		- 4.85	- 4.91		
				Full Range ⁽¹⁾			- 4.85		
			I _O = 5 mA	T _A = 25°C		- 3.5	- 4.1		
Full Range ⁽¹⁾				- 3.5					
A _{VD}	Large-signal differential voltage amplification	V _O = ±4 V	R _L = 10 kΩ			20	50	V/mV	
			Full Range ⁽¹⁾			20			
			R _L = 1 MΩ			300			
r _{id}	Differential input resistance					10 ¹²		Ω	
r _i	Common-mode input resistance					10 ¹²		Ω	
C _i	Common-mode input capacitance	f = 10 kHz, P package				8		pF	
Z _o	Closed-loop output impedance	f = 1 MHz, A _V = 10				130		Ω	
CMRR	Common-mode rejection ratio	V _{IC} = - 5 V to 2.7 V, V _O = 0 V, R _S = 50 Ω	T _A = 25°C		75	80	dB		
			Full Range ⁽¹⁾		75				
k _{SVR}	Supply-voltage rejection ratio (Δ V _{DD} / Δ V _{IO})	V _{DD+} = 2.2 V to ±8 V, V _{IC} = 0 V, no load	T _A = 25°C		80	95	dB		
			Full Range ⁽¹⁾		80				
I _{DD}	Supply current	V _O = 0 V, no load	T _A = 25°C		4.8	6	mA		
			Full Range ⁽¹⁾			6			

6.8 Electrical Characteristics: $V_{DD\pm} = \pm 5\text{ V}$ (TLC2274-Q1 and TLC2274A-Q1) (continued)

at specified free-air temperature, $V_{DD\pm} = \pm 5\text{ V}$; $T_A = 25^\circ\text{C}$, unless otherwise noted.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	$V_O = \pm 2.3\text{ V}$, $R_L = 10\text{ k}\Omega$, $C_L = 100\text{ pF}$	$T_A = 25^\circ\text{C}$	2.3	3.6		V/ μs
			Full Range ⁽¹⁾	1.7			
V_n	Equivalent input noise voltage	$f = 10\text{ Hz}$			50		nV/ $\sqrt{\text{Hz}}$
		$f = 1\text{ kHz}$			9		
V_{NPP}	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz to }1\text{ Hz}$			1		μV
		$f = 0.1\text{ Hz to }10\text{ Hz}$			1.4		
I_n	Equivalent input noise current				0.6		fA/ $\sqrt{\text{Hz}}$
THD+N	Total harmonic distortion + noise	$V_O = \pm 2.3$, $f = 20\text{ kHz}$, $R_L = 10\text{ k}\Omega$	$A_V = 1$		0.0011%		
			$A_V = 10$		0.004%		
			$A_V = 100$		0.03%		
	Gain-bandwidth product	$f = 10\text{ kHz}$, $R_L = 10\text{ k}\Omega$, $C_L = 100\text{ pF}$			2.25		MHz
B_{OM}	Maximum output-swing bandwidth	$V_{O(PP)} = 4.6\text{ V}$, $A_V = 1$, $R_L = 10\text{ k}\Omega$, $C_L = 100\text{ pF}$			0.54		MHz
t_s	Settling time	$A_V = -1$, $R_L = 10\text{ k}\Omega$, Step = $-2.3\text{ V to }2.3\text{ V}$, $C_L = 100\text{ pF}$	To 0.1%		1.5		μs
			To 0.01%		3.2		
ϕ_m	Phase margin at unity gain	$R_L = 10\text{ k}\Omega$, $C_L = 100\text{ pF}$			52°		
	Gain margin	$R_L = 10\text{ k}\Omega$, $C_L = 100\text{ pF}$			10		dB

(1) $T_A = -40^\circ\text{C to }125^\circ\text{C}$.

(2) Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at $T_A = 150^\circ\text{C}$ extrapolated to $T_A = 25^\circ\text{C}$ using the Arrhenius equation and assuming an activation energy of 0.96 eV.

6.9 Typical Characteristics

表 6-1. Table of Graphs

			FIGURE⁽¹⁾
V_{IO}	Input offset voltage	Distribution	1, 2, 3, 4
		vs Common-mode voltage	5, 6
α_{VIO}	Input offset voltage temperature coefficient	Distribution	7, 8, 9, 10 ⁽²⁾
I_{IB} / I_{IO}	Input bias and input offset current	vs Free-air temperature	11 ⁽²⁾
V_I	Input voltage	vs Supply voltage	12
		vs Free-air temperature	13 ⁽²⁾
V_{OH}	High-level output voltage	vs High-level output current	14 ⁽²⁾
V_{OL}	Low-level output voltage	vs Low-level output current	15, 16 ⁽²⁾
V_{OM+}	Maximum positive peak output voltage	vs Output current	17 ⁽²⁾
V_{OM-}	Maximum negative peak output voltage	vs Output current	18 ⁽²⁾
$V_{O(PP)}$	Maximum peak-to-peak output voltage	vs Frequency	19
I_{OS}	Short-circuit output current	vs Supply voltage	20
		vs Free-air temperature	21 ⁽²⁾
V_O	Output voltage	vs Differential input voltage	22, 23
A_{VD}	Large-signal differential voltage amplification	vs Load resistance	24
	Large-signal differential voltage amplification and phase margin	vs Frequency	25, 26
	Large-signal differential voltage amplification	vs Free-air temperature	27 ⁽²⁾ , 28 ⁽²⁾
Z_0	Output impedance	vs Frequency	29, 30
CMRR	Common-mode rejection ratio	vs Frequency	31
		vs Free-air temperature	32
k_{SVR}	Supply-voltage rejection ratio	vs Frequency	33, 34
		vs Free-air temperature	35 ⁽²⁾
I_{DD}	Supply current	vs Supply voltage	36 ⁽²⁾ , 37 ⁽²⁾
		vs Free-air temperature	38 ⁽²⁾ , 39 ⁽²⁾
SR	Slew rate	vs Load Capacitance	40
		vs Free-air temperature	41 ⁽²⁾
V_O	Inverting large-signal pulse response		42, 43
	Voltage-follower large-signal pulse response		44, 45
	Inverting small-signal pulse response		46, 47
	Voltage-follower small-signal pulse response		48, 49
V_n	Equivalent input noise voltage	vs Frequency	50, 51
	Noise voltage over a 10-second period		52
	Integrated noise voltage	vs Frequency	53
THD+N	Total harmonic distortion + noise	vs Frequency	54
	Gain-bandwidth product	vs Supply voltage	55
		vs Free-air temperature	56 ⁽²⁾
ϕ_m	Phase margin	vs Load capacitance	57
	Gain margin	vs Load capacitance	58

(1) For all graphs where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V.

(2) Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

6.9 Typical Characteristics (continued)

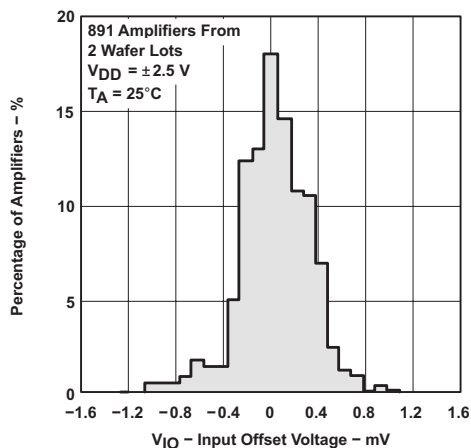


图 6-1. Distribution of TLC2272-Q1 Input Offset Voltage

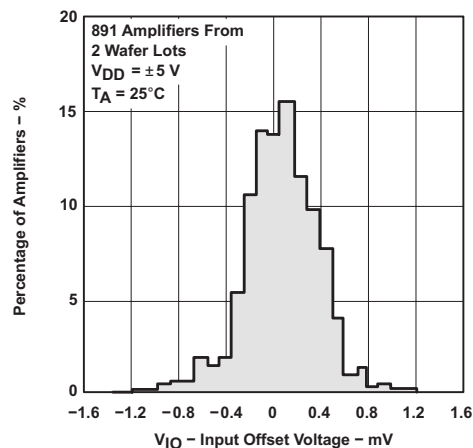


图 6-2. Distribution of TLC2272-Q1 Input Offset Voltage

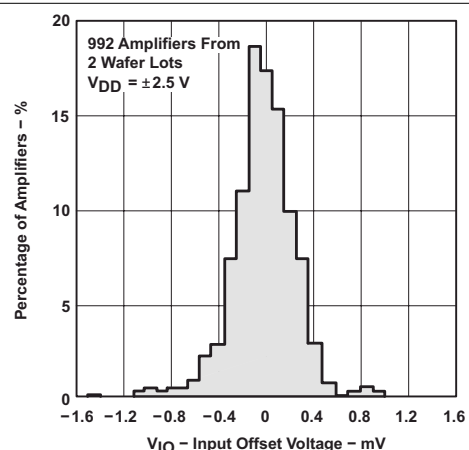


图 6-3. Distribution of TLC2274-Q1 Input Offset Voltage

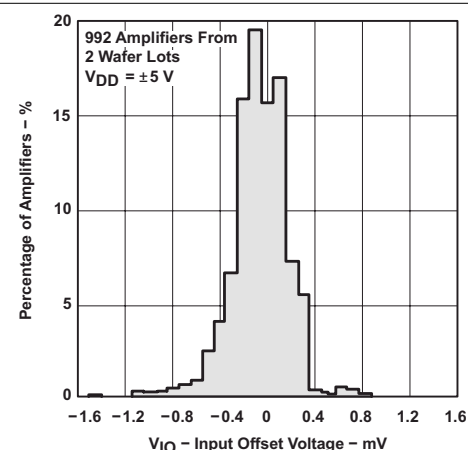


图 6-4. Distribution of TLC2274-Q1 Input Offset Voltage

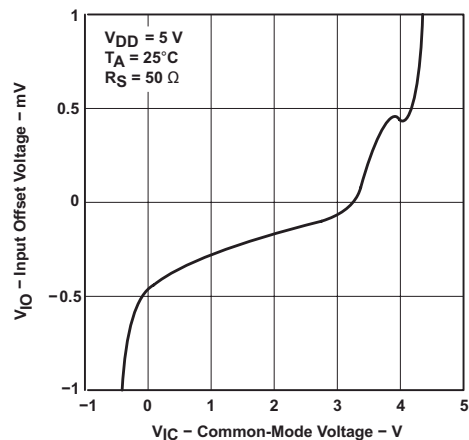


图 6-5. Input Offset Voltage vs Common-Mode Voltage

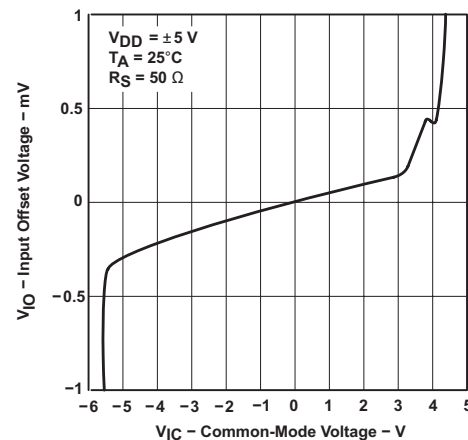


图 6-6. Input Offset Voltage vs Common-Mode Voltage

6.9 Typical Characteristics (continued)

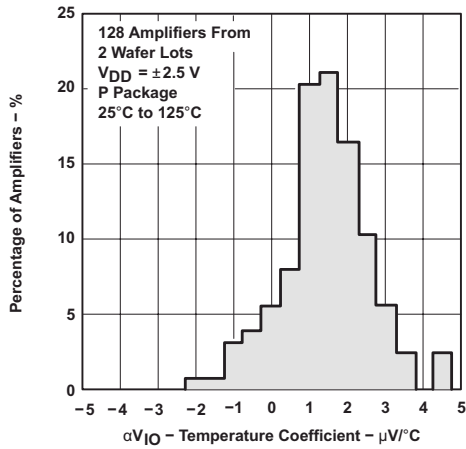


图 6-7. Distribution of TLC2272-Q1 vs Input Offset Voltage Temperature Coefficient

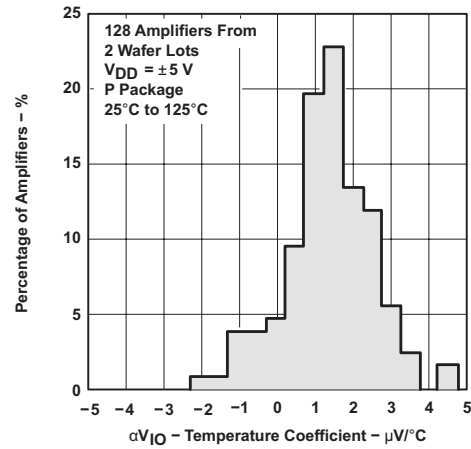


图 6-8. Distribution of TLC2272-Q1 vs Input Offset Voltage Temperature Coefficient

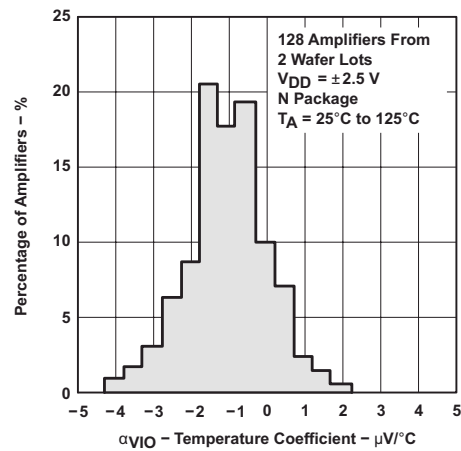


图 6-9. Distribution of TLC2274-Q1 vs Input Offset Voltage Temperature Coefficient

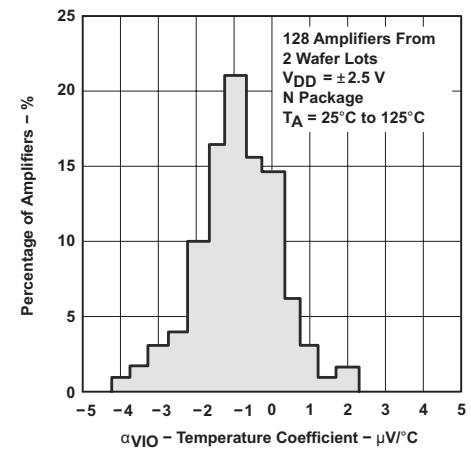


图 6-10. Distribution of TLC2274-Q1 vs Input Offset Voltage Temperature Coefficient

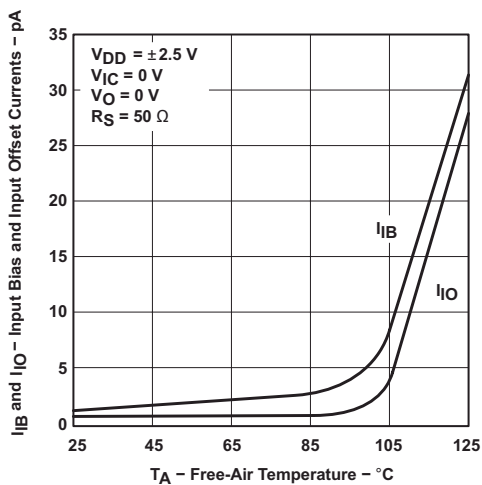


图 6-11. Input Bias and Input Offset Current vs Free-Air Temperature

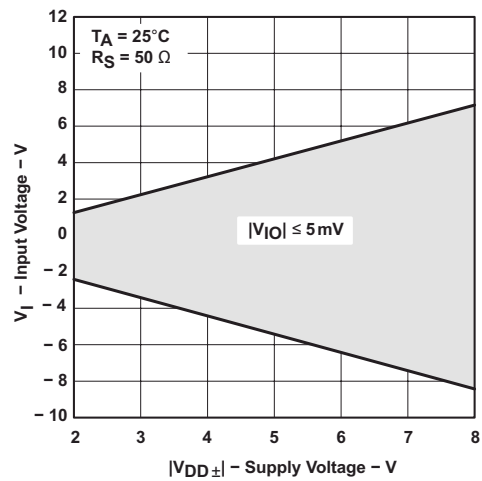


图 6-12. Input Voltage vs Supply Voltage

6.9 Typical Characteristics (continued)

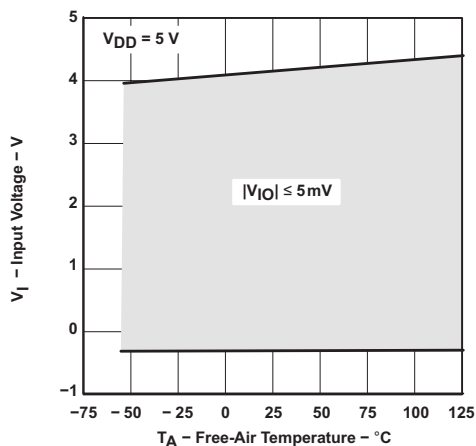


图 6-13. Input Voltage vs Free-Air Temperature

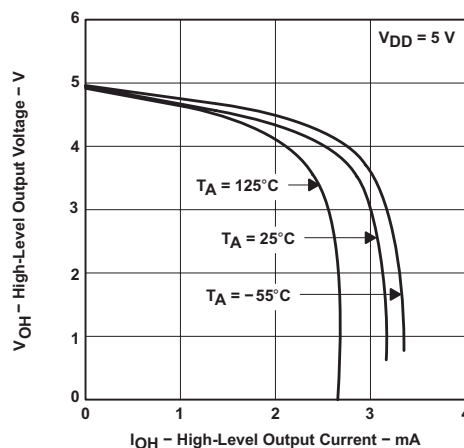


图 6-14. High-Level Output Voltage vs High-Level Output Current

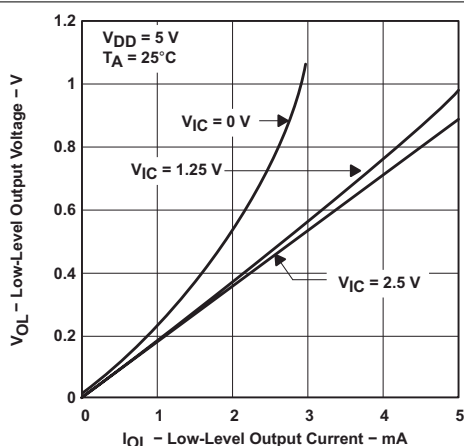


图 6-15. Low-Level Output Voltage vs Low-Level Output Current

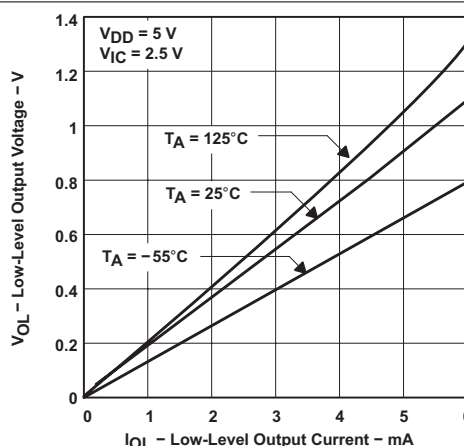


图 6-16. Low-Level Output Voltage vs Low-Level Output Current

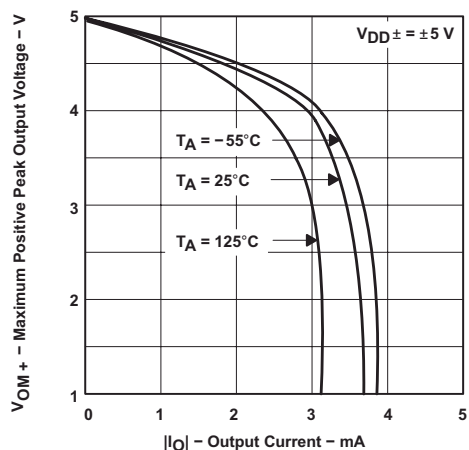


图 6-17. Maximum Positive Peak Output Voltage vs Output Current

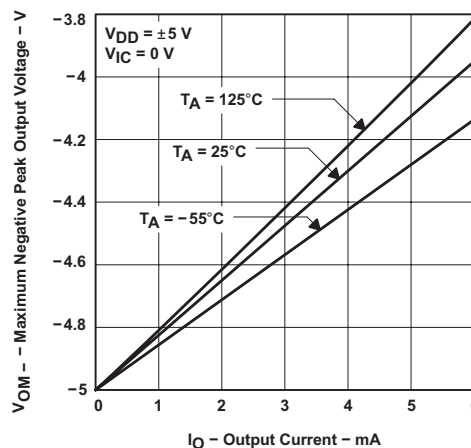


图 6-18. Maximum Positive Peak Output Voltage vs Output Current

6.9 Typical Characteristics (continued)

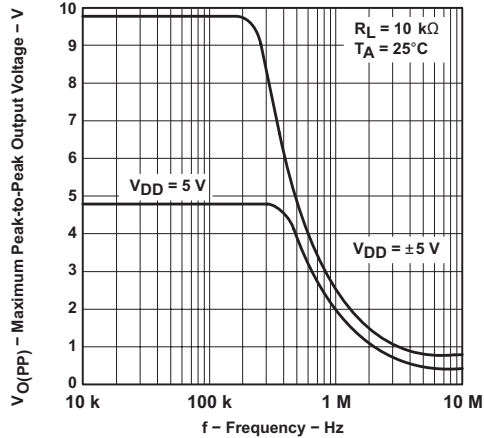


图 6-19. Maximum Peak-to-Peak Output Voltage vs Frequency

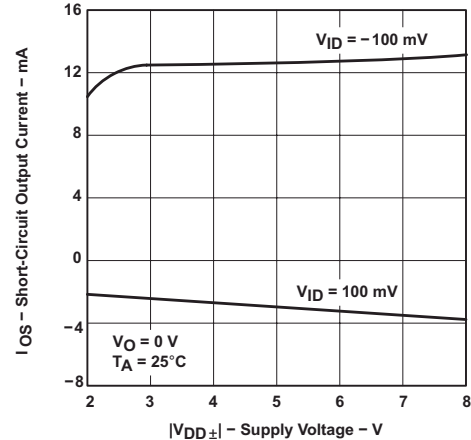


图 6-20. Short-Circuit Output Current vs Supply Voltage

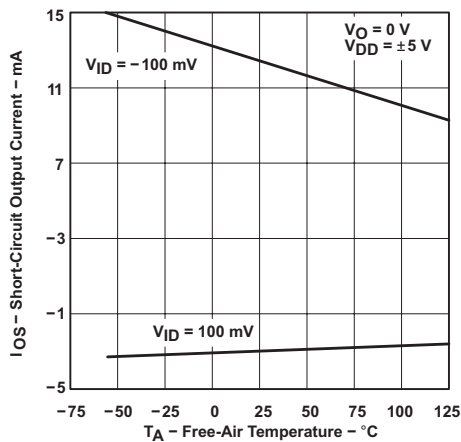


图 6-21. Short-Circuit Output Current vs Free-Air Temperature

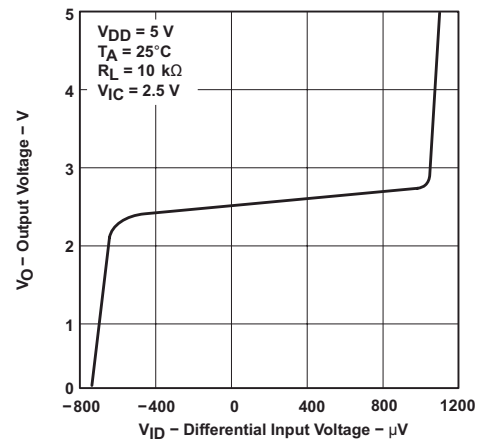


图 6-22. Output Voltage vs Differential Input Voltage

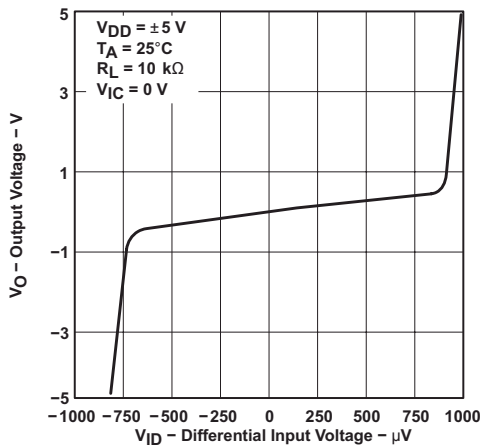


图 6-23. Output Voltage vs Differential Input Voltage

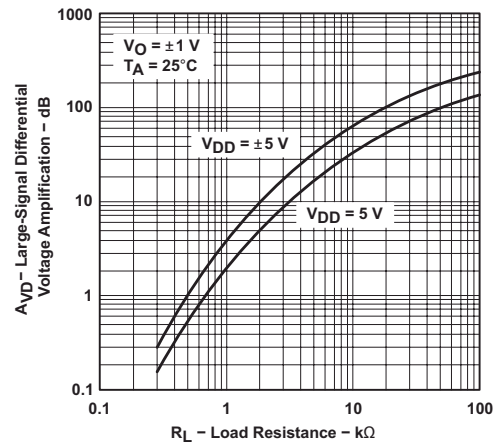


图 6-24. Large-Signal Differential Voltage Amplification vs Load Resistance

6.9 Typical Characteristics (continued)

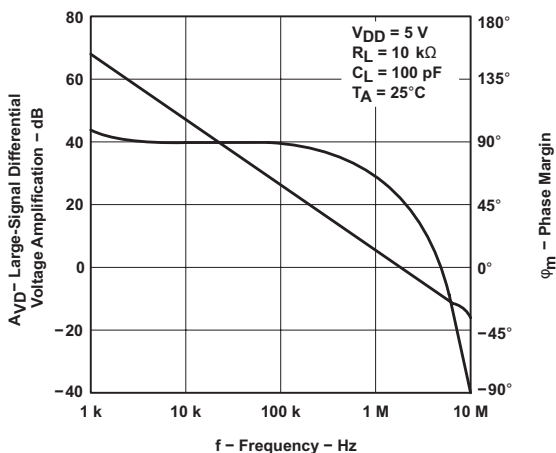


图 6-25. Large-Signal Differential Voltage Amplification and Phase Margin vs Frequency

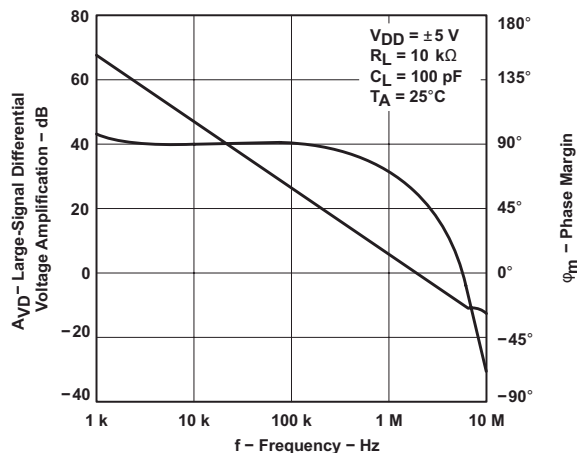


图 6-26. Large-Signal Differential Voltage Amplification and Phase Margin vs Frequency

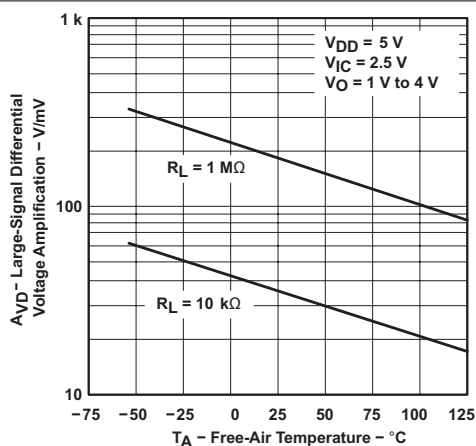


图 6-27. Large-Signal Differential Voltage Amplification vs Free-Air Temperature

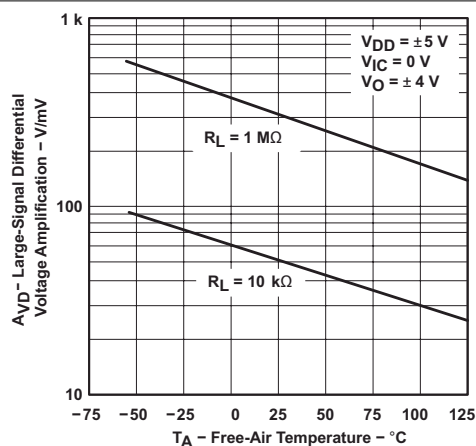


图 6-28. Large-Signal Differential Voltage Amplification vs Free-Air Temperature

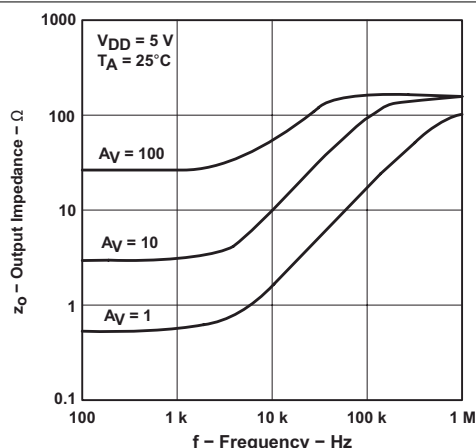


图 6-29. Output Impedance vs Frequency

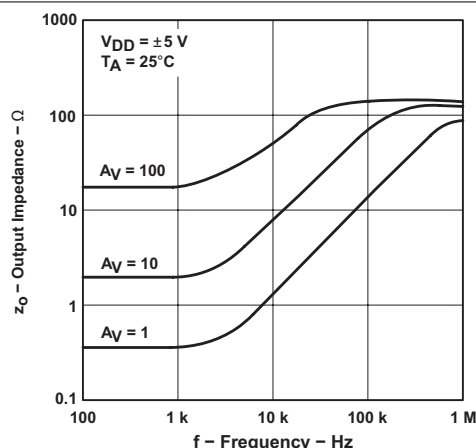


图 6-30. Output Impedance vs Frequency

6.9 Typical Characteristics (continued)

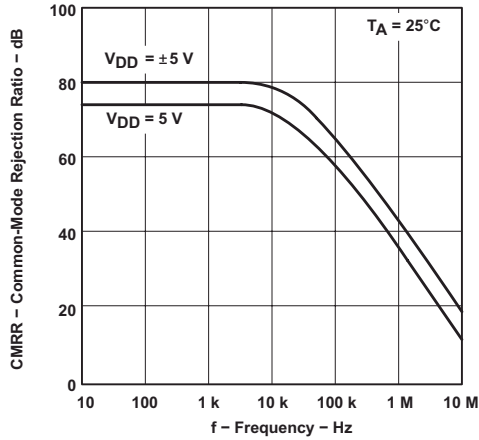


图 6-31. Common-Mode Rejection Ratio vs Frequency

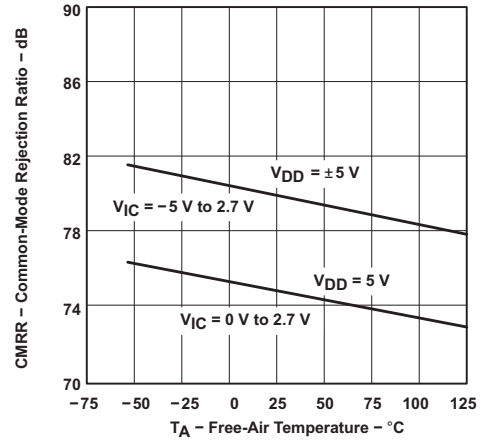


图 6-32. Common-Mode Rejection Ratio vs Free-Air Temperature

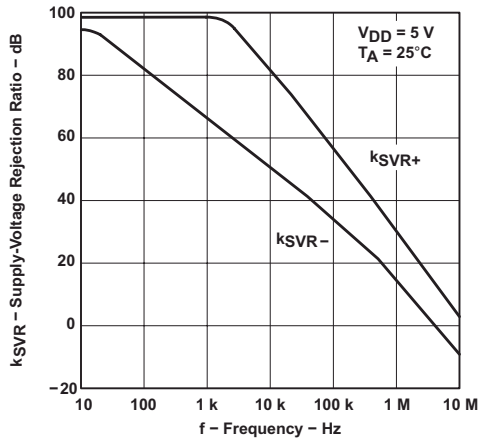


图 6-33. Supply-Voltage Rejection Ratio vs Frequency

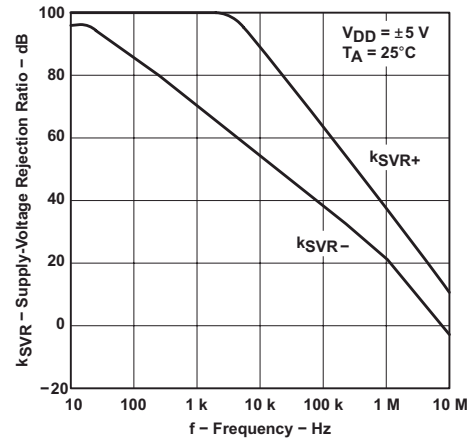


图 6-34. Supply-Voltage Rejection Ratio vs Frequency

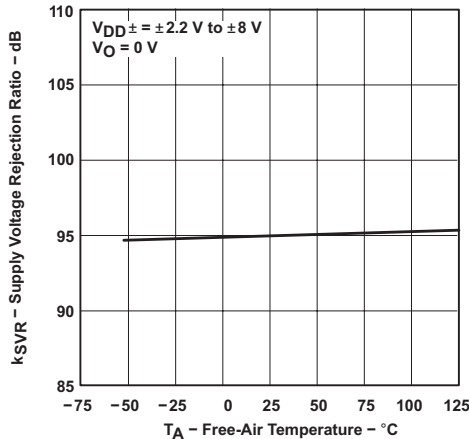


图 6-35. Supply-Voltage Rejection Ratio vs Free-Air Temperature

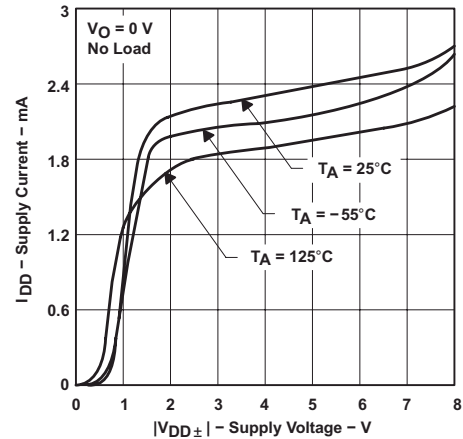


图 6-36. TLC2272-Q1 Supply Current vs Supply Voltage

6.9 Typical Characteristics (continued)

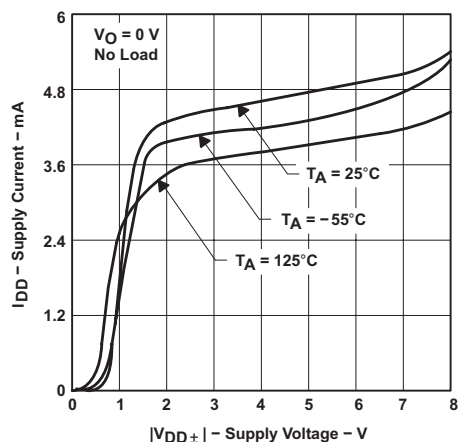


图 6-37. TLC2274-Q1 Supply Current vs Supply Voltage

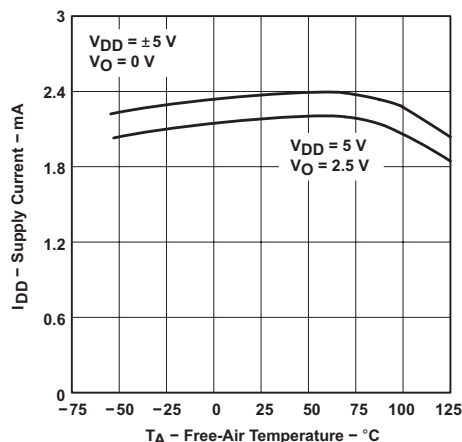


图 6-38. TLC2272-Q1 Supply Current vs Free-Air Temperature

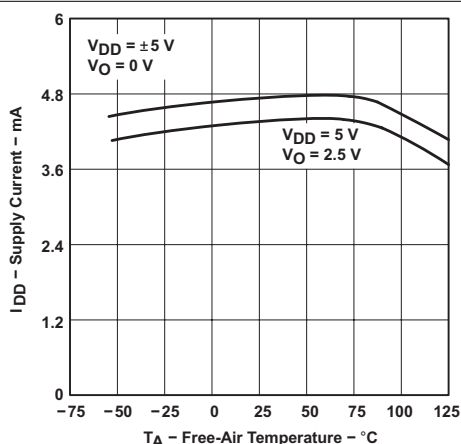


图 6-39. TLC2274-Q1 Supply Current vs Free-Air Temperature

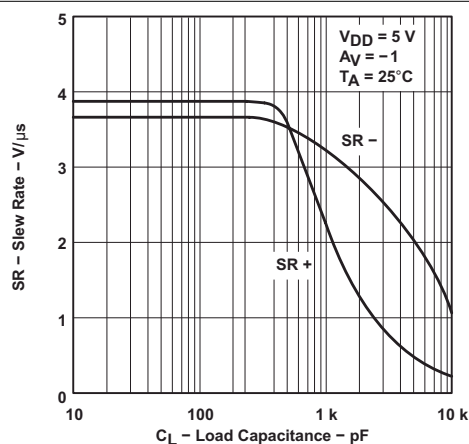


图 6-40. Slew Rate vs Load Capacitance

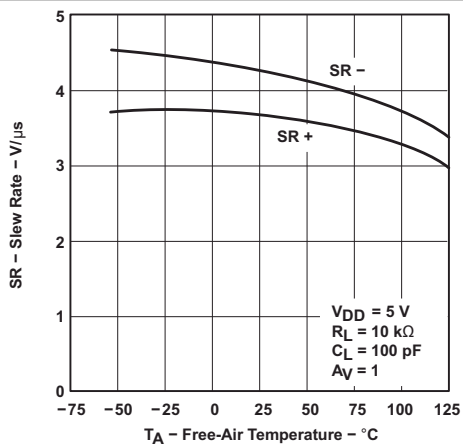


图 6-41. Slew Rate vs Free-Air Temperature

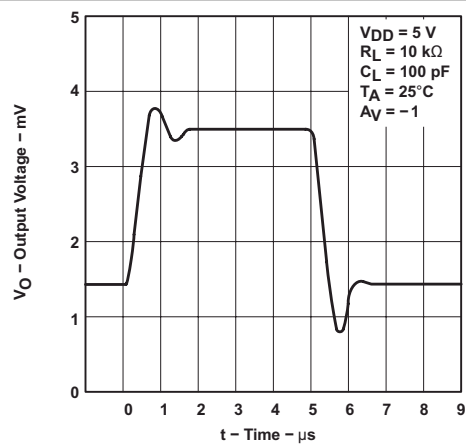


图 6-42. Inverting Large-Signal Pulse Response

6.9 Typical Characteristics (continued)

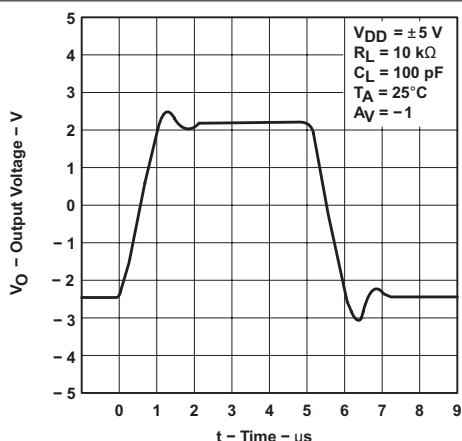


图 6-43. Inverting Large-Signal Pulse Response

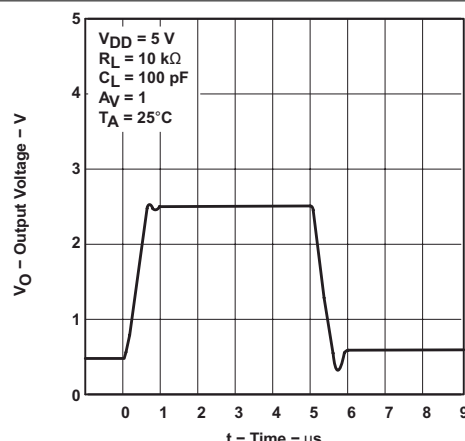


图 6-44. Voltage-Follower Large-Signal Pulse Response

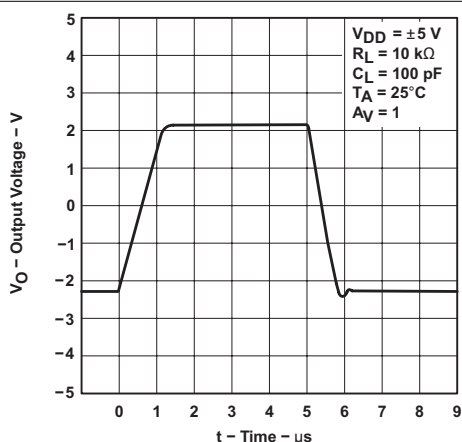


图 6-45. Voltage-Follower Large-Signal Pulse Response

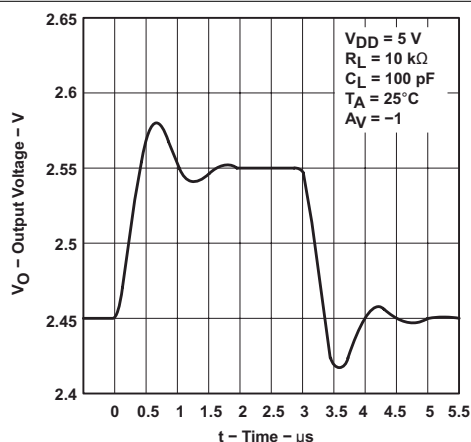


图 6-46. Inverting Small-Signal Pulse Response

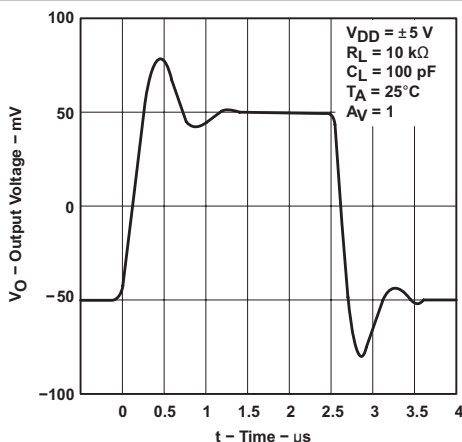


图 6-47. Inverting Small-Signal Pulse Response

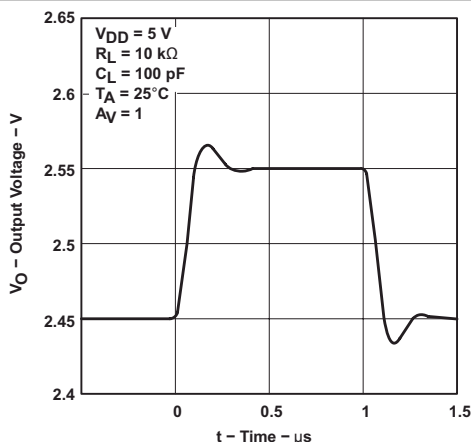


图 6-48. Voltage-Follower Small-Signal Pulse Response

6.9 Typical Characteristics (continued)

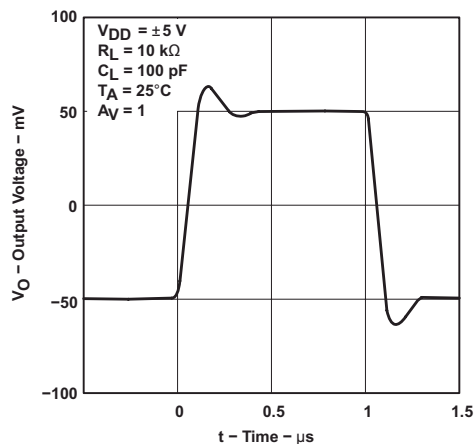


图 6-49. Voltage-Follower Small-Signal Pulse Response

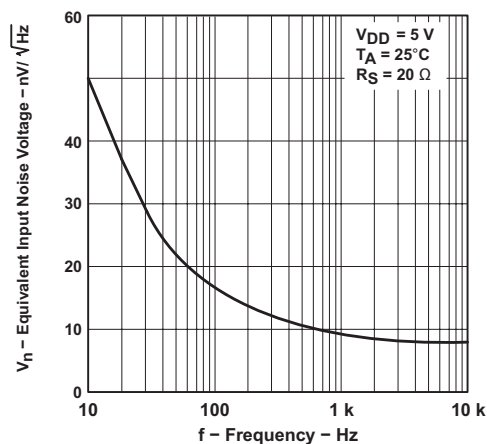


图 6-50. Equivalent Input Noise Voltage vs Frequency

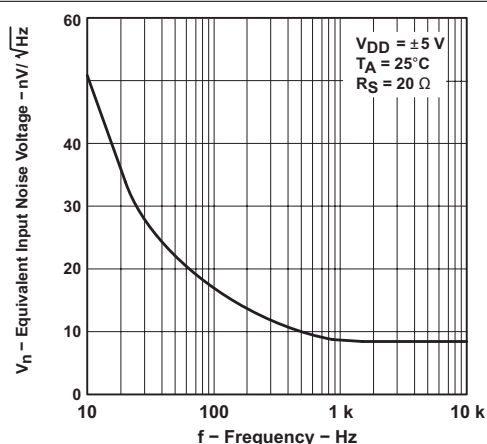


图 6-51. Equivalent Input Noise Voltage vs Frequency

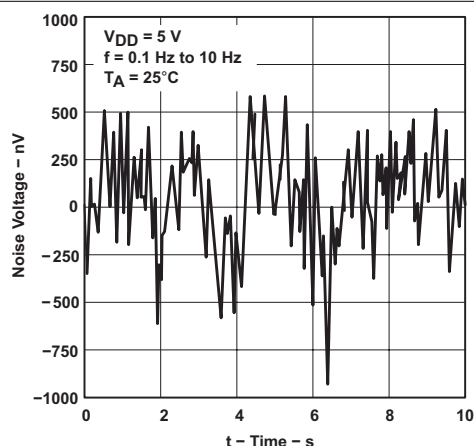


图 6-52. Noise Voltage Over a 10 Second Period

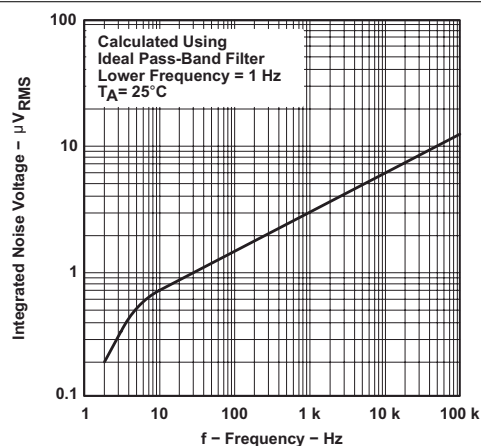


图 6-53. Integrated Noise Voltage vs Frequency

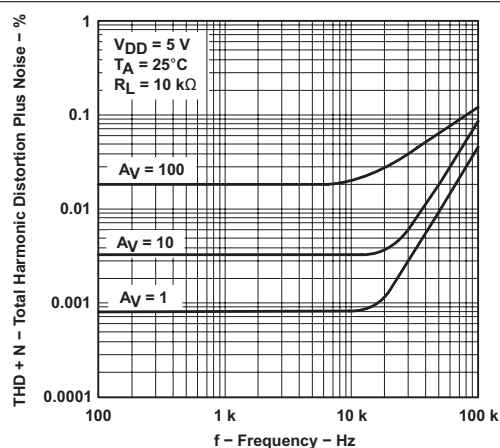


图 6-54. Total Harmonic Distortion + Noise vs Frequency

6.9 Typical Characteristics (continued)

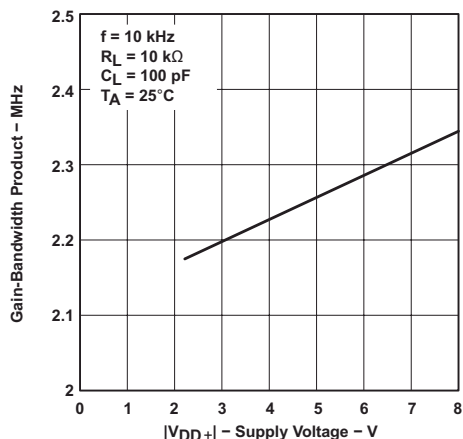


图 6-55. Gain-Bandwidth Product vs Supply Voltage

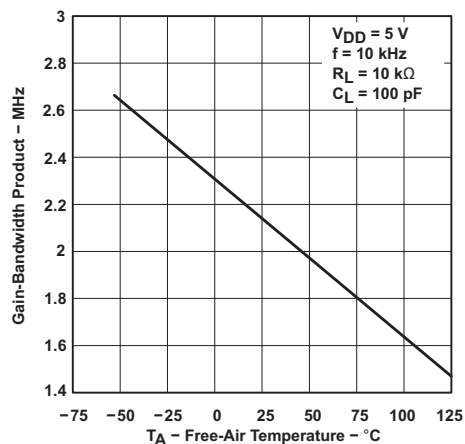


图 6-56. Gain-Bandwidth Product vs Free-Air Temperature

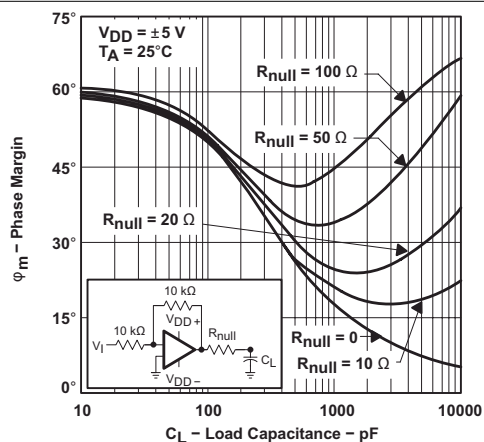


图 6-57. Phase Margin vs Load Capacitance

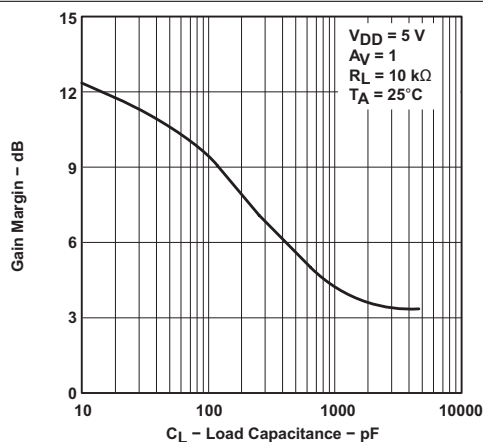


图 6-58. Gain Margin vs Load Capacitance

7 Detailed Description

7.1 Overview

The TLC227x-Q1 devices are a rail-to-rail output operational amplifiers. These devices operate from a 4.4-V to 16-V single supply and a ± 2.2 -V ± 8 -V dual supply, are unity-gain stable, and are an excellent choice for a wide range of general-purpose applications.

7.2 Functional Block Diagram

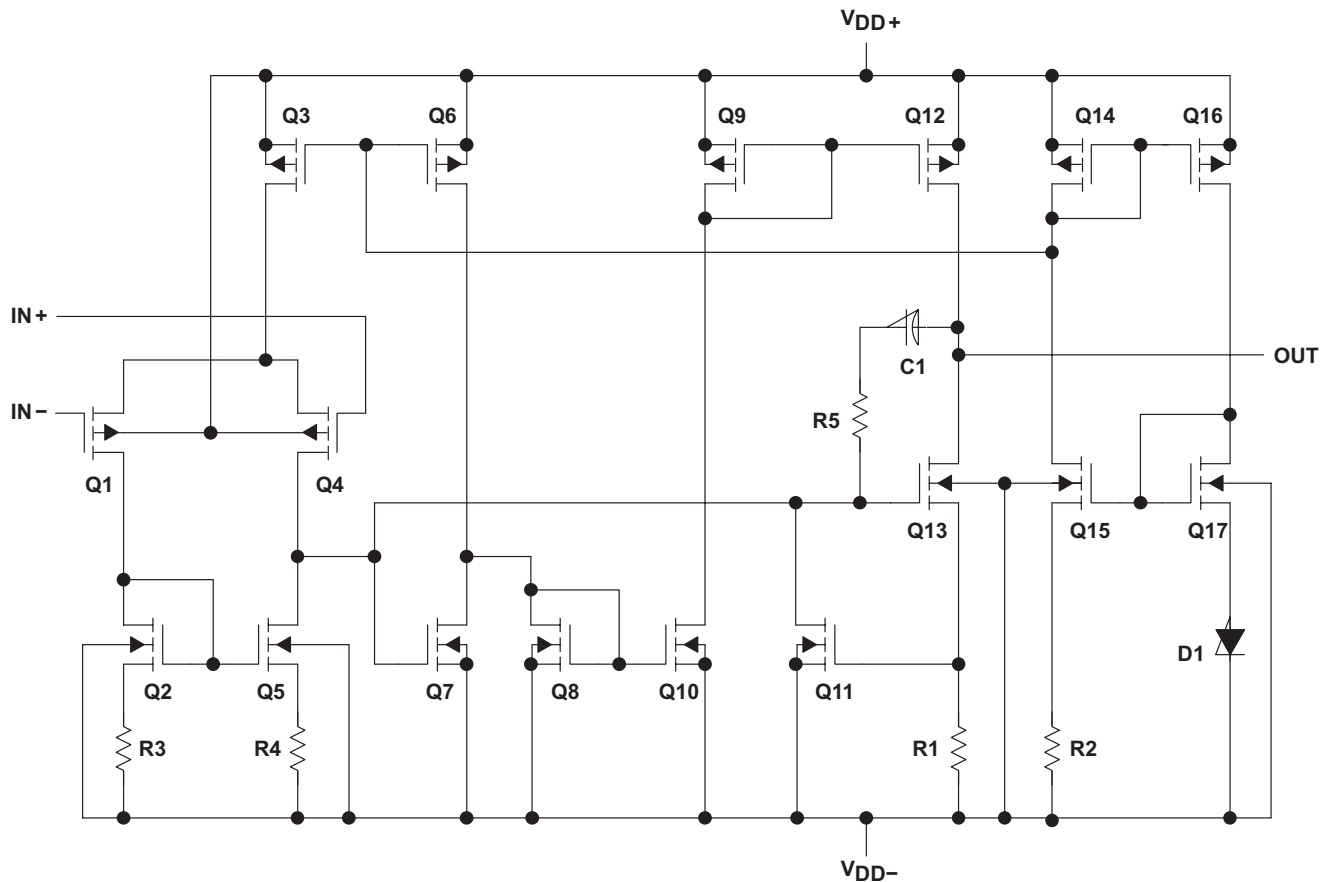


表 7-1. Actual Device Component Count⁽¹⁾

COMPONENT	TLC2272-Q1	TLC2274-Q1
Transistors	38	76
Resistors	26	52
Diodes	9	18
Capacitors	3	6

(1) Includes both amplifiers and all ESD, bias, and trim circuitry.

7.3 Feature Description

The TLC227x-Q1 family features 2-MHz bandwidth and voltage noise of $9 \text{ nV}/\sqrt{\text{Hz}}$ with performance rated from 4.4 V to 16 V across an automotive temperature range (–40°C to +125°C). LinMOS is a great choice for a wide range of audio, automotive, industrial, and instrumentation applications.

7.4 Device Functional Modes

The TLC227x-Q1 family of devices is powered on when the supply is connected. The device can operate with single or dual supply, depending on the application. The device is in full performance after the supply is greater than the recommended value.

8.2 Typical Application

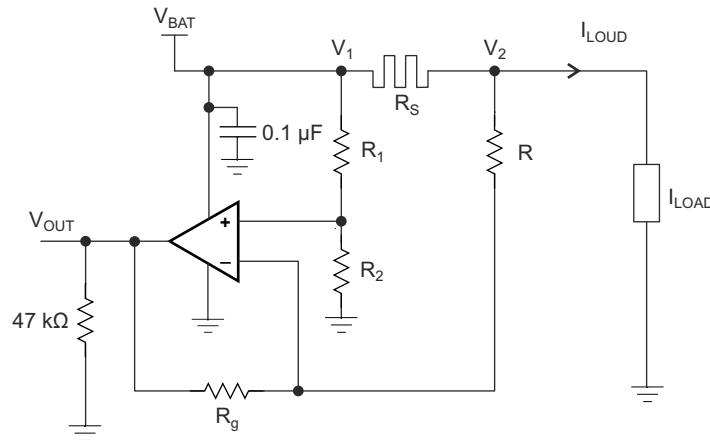


图 8-2. High-Side Current Monitor Equivalent Schematic (Each Amplifier)

8.2.1 Design Requirements

For this design example, use these parameters listed in 表 8-1 as the input parameters.

表 8-1. Design Parameters

PARAMETER	VALUE
V _{BAT}	Battery voltage 12 V
R _{SENSE}	Sense resistor 0.1 Ω
I _{LOAD}	Load current 0 A to 10 A
	Operational amplifier Set in differential configuration with gain = 10

8.2.2 Detailed Design Procedure

This circuit is designed for measuring the high-side current in automotive body control modules with a 12-V battery or similar applications. The operational amplifier is set as differential with an external resistor network.

8.2.2.1 Differential Amplifier Equations

方程式 1 和 方程式 2 are used to calculate V_{OUT}.

$$V_{OUT} = \frac{R_g}{R} \left(\frac{\frac{R}{R_g} - \frac{R_1}{R_2}}{1 + \frac{R_1}{R_2}} \times \frac{V_1 + V_2}{2} + \frac{1 + \frac{1}{2} \left(\frac{R_1}{R_2} + \frac{R}{R_g} \right)}{1 + \frac{R_1}{R_2}} (V_1 - V_2) \right) \quad (1)$$

$$V_{OUT} = \frac{R_g}{R} \left(\frac{\frac{R}{R_g} - \frac{R_1}{R_2}}{1 + \frac{R_1}{R_2}} \times V_{BAT} + \frac{1 + \frac{1}{2} \left(\frac{R_1}{R_2} + \frac{R}{R_g} \right)}{1 + \frac{R_1}{R_2}} \times R_S \times I_{LOAD} \right) \quad (2)$$

In an ideal case, 方程式 3 then calculates R₁ = R and R₂ = R_g, and V_{OUT}:

$$V_{OUT} = \frac{R_g}{R} \times R_S \times I_{LOAD} \quad (3)$$

However, the resistors have tolerances; therefore, the resistors cannot be perfectly matched.

$$R_1 = R \pm \Delta R_1$$

$$R_2 = R \pm \Delta R_2$$

$$R = R \pm \Delta R$$

$$R_g = R_g \pm \Delta R_g$$

$$Tol = \frac{\Delta R}{R} \quad (4)$$

方程式 5 shows that by developing the equations and neglecting the second order, the worst case is when the tolerances add up:

$$V_{OUT} = \pm (4 Tol) \frac{R_g}{R + R_g} \times V_{BAT} + \left(1 \pm 2 Tol \left(1 + \frac{2R}{R + R_g} \right) \right) \frac{R_g}{R} \times R_S \times I_{LOAD} \quad (5)$$

where

- Tol = 0.01 for 1%
- Tol = 0.001 for 0.1%

If the resistors are perfectly matched, then Tol = 0 and 方程式 6 calculates V_{OUT} :

$$V_{OUT} = \frac{R_g}{R} \times R_S \times I_{LOAD} \quad (6)$$

The highest error is from the common mode:

$$4 (Tol) \frac{R_g}{R + R_g} \times V_{BAT} \quad (7)$$

Gain of 10, $R_g / R = 10$, and Tol = 1%:

$$\text{Common mode error} = ((4 \times 0.01) / 1.1) \times 12 \text{ V} = 0.436 \text{ V}$$

Gain of 10 and Tol = 0.1%:

$$\text{Common mode error} = 43.6 \text{ mV}$$

The resistors were chosen from 2% batches.

R_1 and R 12 k Ω

R_2 and R_g 120 k Ω

$$\text{Ideal Gain} = 120 / 12 = 10$$

The measured value of the resistors:

$$R_1 = 11.835 \text{ k}\Omega$$

$$R = 11.85 \text{ k}\Omega$$

$$R_2 = 117.92 \text{ k}\Omega$$

$$R_g = 118.07 \text{ k}\Omega$$

8.2.3 Application Curves

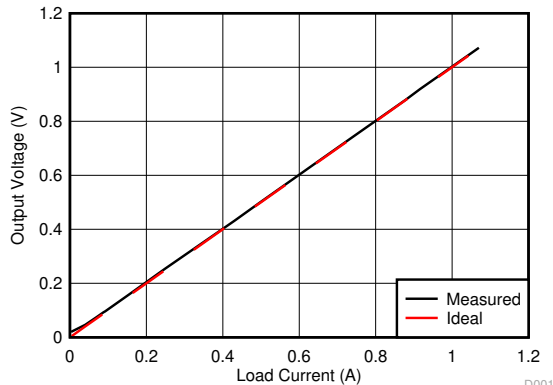


图 8-3. Output Voltage Measured vs Ideal
(0 A to 1 A)

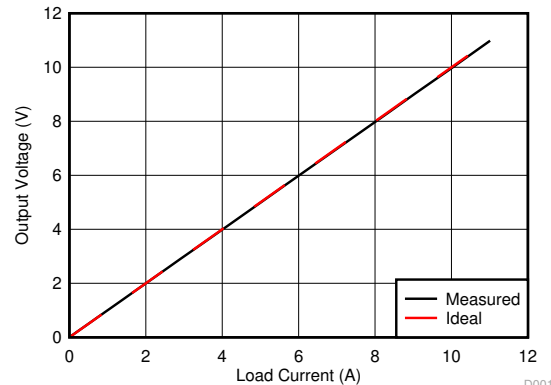


图 8-4. Output Voltage Measured vs Ideal
(0 A to 10 A)

8.3 Power Supply Recommendations

Supply voltage is 4.4 V to 16 V for single supply and ± 2.2 V to ± 8 V for dual. In the high-side sensing application, the supply is connected to a 12-V battery.

8.4 Layout

8.4.1 Layout Guidelines

The TLC227x-Q1 is a wideband amplifier. To realize the full operational performance of the device, good high frequency printed-circuit-board (PCB) layout practices are required. Low-loss 0.1- μ F bypass capacitors must be connected between each supply pin and ground as close to the device as possible. The bypass capacitor traces must be designed for minimum inductance.

8.4.2 Layout Example

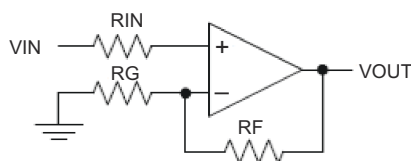


图 8-5. Schematic Representation

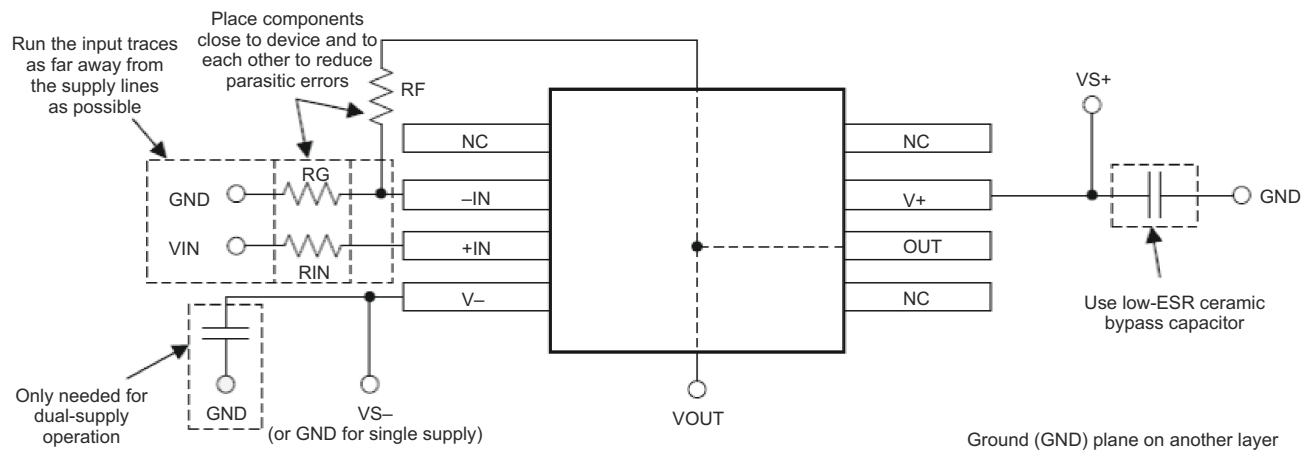


图 8-6. Operational Amplifier Board Layout for Noninverting Configuration

9 Device and Documentation Support

9.1 Device Support

9.1.1 Development Support

9.1.1.1 PSpice® for TI

PSpice® for TI 是可帮助评估模拟电路性能的设计和仿真环境。在进行布局和制造之前创建子系统设计和原型解决方案，可降低开发成本并缩短上市时间。

9.1.1.2 TINA-TI™ Simulation Software (Free Download)

TINA-TI™ simulation software is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI simulation software is a free, fully-functional version of the TINA™ software, preloaded with a library of macromodels, in addition to a range of both passive and active models. TINA-TI simulation software provides all the conventional dc, transient, and frequency domain analysis of SPICE, as well as additional design capabilities.

Available as a [free download](#) from the [Design tools and simulation](#) web page, TINA-TI simulation software offers extensive post-processing capability that allows users to format results in a variety of ways. Virtual instruments offer the ability to select input waveforms and probe circuit nodes, voltages, and waveforms, creating a dynamic quick-start tool.

备注

These files require that either the TINA software or TINA-TI software be installed. Download the free TINA-TI simulation software from the [TINA-TI™ software folder](#).

9.2 Documentation Support

9.2.1 Related Documentation

For related documentation see the following:

- G.R. Boyle, D.O. Pederson, B.M. Cohn, J.E. Solomon (Dec. 1974). *Macromodeling of Integrated Circuit Operational Amplifiers*. IEEE Journal of Solid-State Circuits, Volume 9, Issue 6, pages 353 – 364. Retrieved from <https://ieeexplore.ieee.org/document/1050528>

9.3 接收文档更新通知

要接收文档更新通知，请导航至 [ti.com](https://www.ti.com) 上的器件产品文件夹。点击 [订阅更新](#) 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。

9.4 支持资源

[TI E2E™ 支持论坛](#) 是工程师的重要参考资料，可直接从专家获得快速、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可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](#)》。

9.5 Trademarks

LinCMOS™, TINA-TI™, and TI E2E™ are trademarks of Texas Instruments.

TINA™ is a trademark of DesignSoft, Inc.

PSpice® is a registered trademark of Cadence Design Systems, Inc.

所有商标均为其各自所有者的财产。

9.6 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

9.7 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。

10 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)
TLC2272AQDRG4Q1	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQDRG4Q1.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQDRG4Q1.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQDRQ1	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQDRQ1.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQDRQ1.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQPWRG4Q1	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQPWRG4Q1.A	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQPWRG4Q1.B	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQPWRQ1	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQPWRQ1.A	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272AQPWRQ1.B	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272AQ
TLC2272QDRG4Q1	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QDRG4Q1.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QDRG4Q1.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QDRQ1	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QDRQ1.A	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QDRQ1.B	Active	Production	SOIC (D) 8	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QPWRG4Q1	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QPWRG4Q1.A	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QPWRG4Q1.B	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QPWRQ1	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QPWRQ1.A	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2272QPWRQ1.B	Active	Production	TSSOP (PW) 8	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2272Q1
TLC2274AQDRG4Q1	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQDRG4Q1.A	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQDRG4Q1.B	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQDRQ1	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQDRQ1.A	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1

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)
TLC2274AQDRQ1.B	Active	Production	SOIC (D) 14	2500 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQPWRG4Q1	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQPWRG4Q1.A	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQPWRG4Q1.B	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQPWRQ1	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQPWRQ1.A	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274AQPWRQ1.B	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274AQ1
TLC2274QDRG4Q1	Obsolete	Production	SOIC (D) 14	-	-	Call TI	Call TI	-40 to 125	2274Q1
TLC2274QDRQ1	Obsolete	Production	SOIC (D) 14	-	-	Call TI	Call TI	-40 to 125	2274Q1
TLC2274QPWRG4Q1	Obsolete	Production	TSSOP (PW) 14	-	-	Call TI	Call TI	-40 to 125	2274Q1
TLC2274QPWRQ1	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274Q1
TLC2274QPWRQ1.A	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274Q1
TLC2274QPWRQ1.B	Active	Production	TSSOP (PW) 14	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	2274Q1

⁽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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OTHER QUALIFIED VERSIONS OF TLC2272-Q1, TLC2272A-Q1, TLC2274-Q1, TLC2274A-Q1 :

- Catalog : [TLC2272](#), [TLC2272A](#), [TLC2274](#), [TLC2274A](#)
- Enhanced Product : [TLC2272A-EP](#), [TLC2274-EP](#), [TLC2274A-EP](#)
- Military : [TLC2272M](#), [TLC2272AM](#), [TLC2274AM](#)

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product
- Enhanced Product - Supports Defense, Aerospace and Medical Applications
- Military - QML certified for Military and Defense Applications

TAPE AND REEL INFORMATION



*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
TLC2272AQPWRG4Q1	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC2272AQPWRQ1	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC2272QPWRG4Q1	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC2272QPWRQ1	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC2274AQPWRG4Q1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TLC2274AQPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TLC2274QPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TLC2272AQPWRG4Q1	TSSOP	PW	8	2000	353.0	353.0	32.0
TLC2272AQPWRQ1	TSSOP	PW	8	2000	353.0	353.0	32.0
TLC2272QPWRG4Q1	TSSOP	PW	8	2000	353.0	353.0	32.0
TLC2272QPWRQ1	TSSOP	PW	8	2000	353.0	353.0	32.0
TLC2274AQPWRG4Q1	TSSOP	PW	14	2000	353.0	353.0	32.0
TLC2274AQPWRQ1	TSSOP	PW	14	2000	353.0	353.0	32.0
TLC2274QPWRQ1	TSSOP	PW	14	2000	353.0	353.0	32.0

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

SMALL OUTLINE INTEGRATED CIRCUIT



4220718/A 09/2016

NOTES:

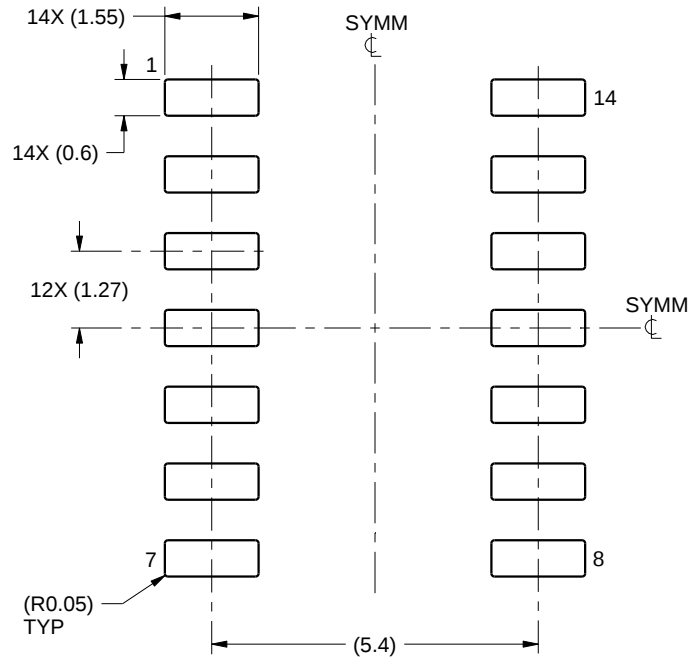
1. All linear dimensions are in millimeters. Dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate 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

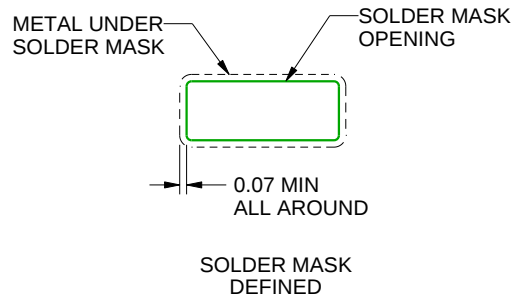
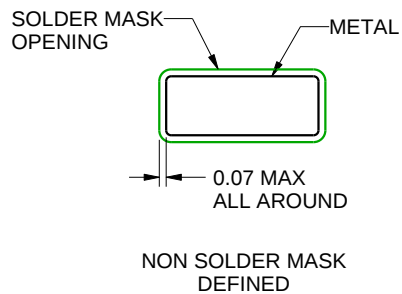
D0014A

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.

EXAMPLE BOARD LAYOUT

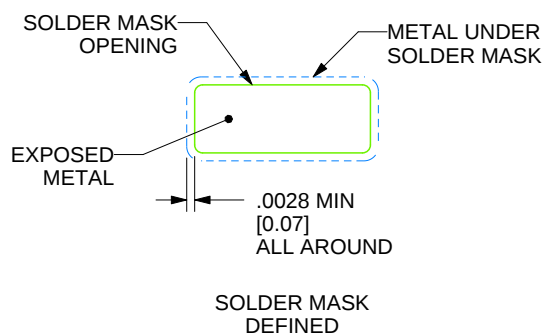
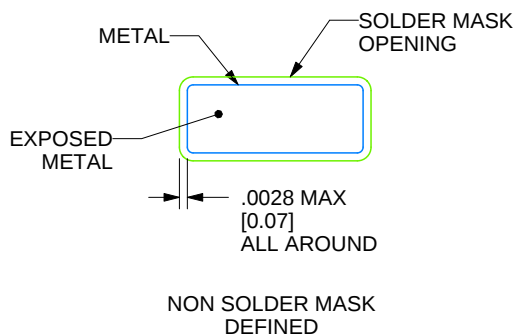
D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X



SOLDER MASK DETAILS

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

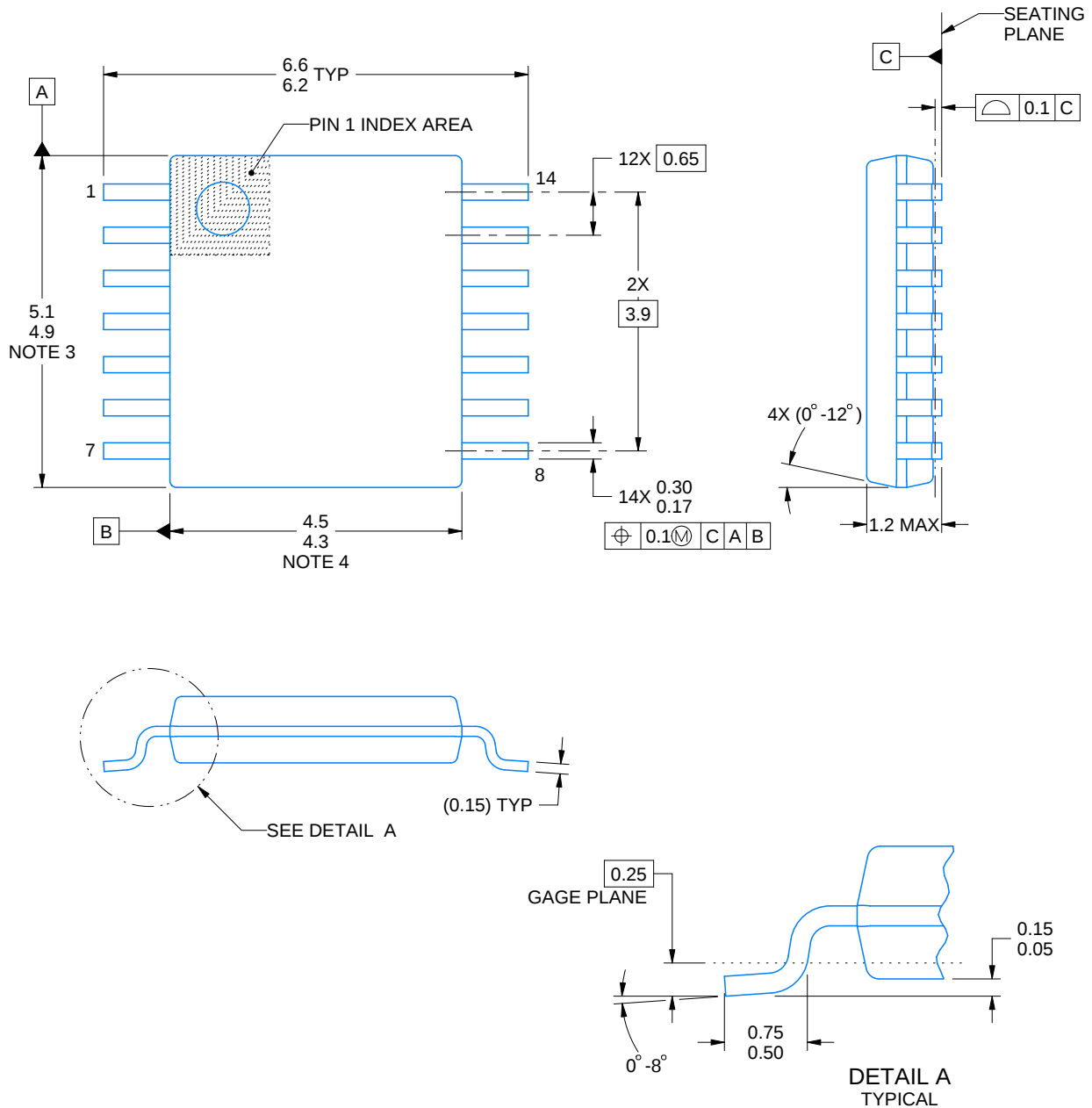
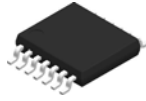


SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

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.



4220202/B 12/2023

NOTES:

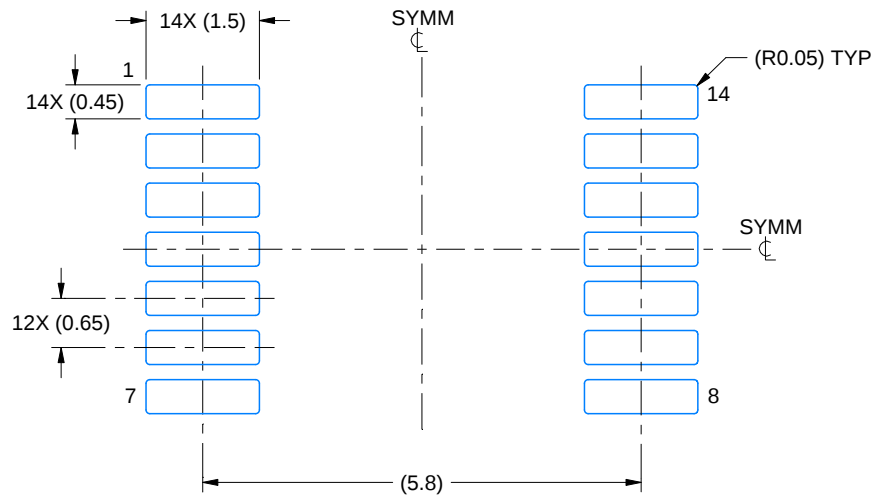
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153.

EXAMPLE BOARD LAYOUT

PW0014A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 10X



SOLDER MASK DETAILS

4220202/B 12/2023

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

PW0014A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE: 10X

4220202/B 12/2023

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.

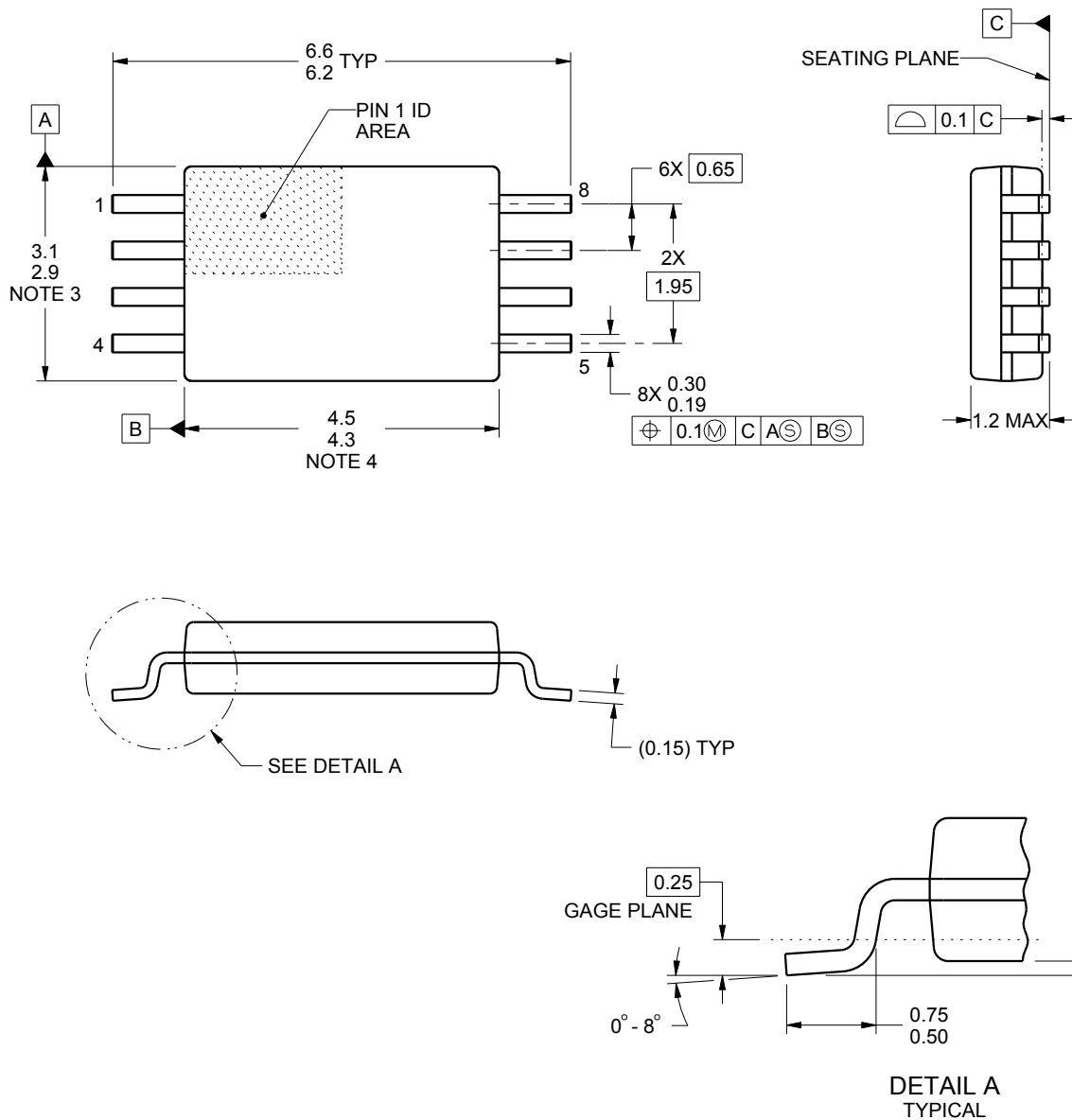
PW0008A



PACKAGE OUTLINE

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



4221848/A 02/2015

NOTES:

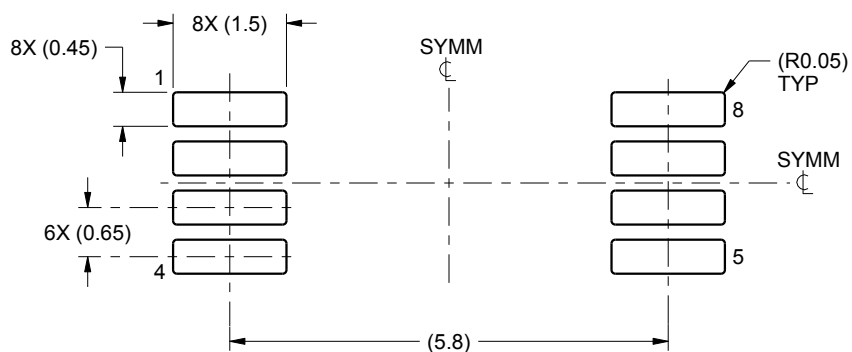
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153, variation AA.

EXAMPLE BOARD LAYOUT

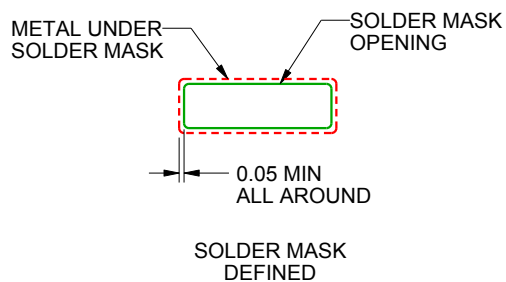
PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
SCALE:10X



SOLDER MASK DETAILS
NOT TO SCALE

4221848/A 02/2015

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

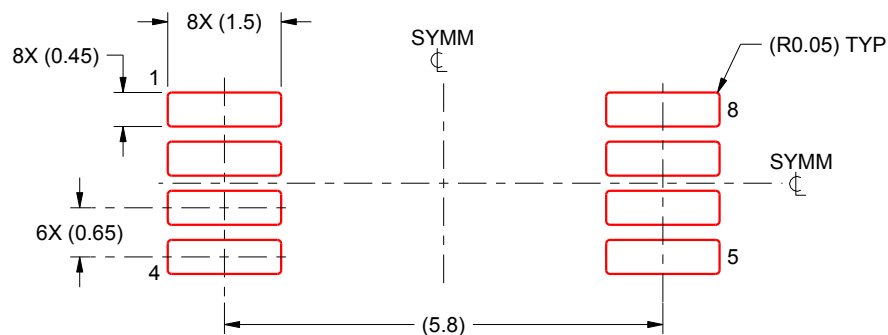
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:10X

4221848/A 02/2015

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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