

- Qualified for Automotive Applications
- ESD Protection Exceeds 2000 V Per MIL-STD-883, Method 3015; Exceeds 200 V Using Machine Model (C = 200 pF, R = 0)
- Output Swing includes Both Supply Rails
- Low Noise . . . 12 nV/√Hz Typ at f = 1 kHz
- Low Input Bias Current . . . 1 pA Typ
- Fully Specified for Both Single-Supply and Split-Supply Operation
- Low Power . . . 500 μA Max
- Common-Mode Input Voltage Range Includes Negative Rail
- Low Input Offset Voltage  
950 μV Max at T<sub>A</sub> = 25°C (TLC2262A)
- Macromodel Included
- Performance Upgrade for the TS27M2/M4 and TLC27M2/M4

## description

The TLC2262 and TLC2264 are dual and quadruple operational amplifiers from Texas Instruments. Both devices exhibit rail-to-rail output performance for increased dynamic range in single- or split-supply applications. The TLC226x family offers a compromise between the micropower TLC225x and the ac performance of the TLC227x. It has low supply current for battery-powered applications, while still having adequate ac performance for applications that demand it. The noise performance has been dramatically improved over previous generations of CMOS amplifiers. Figure 1 depicts the low level of noise voltage for this CMOS amplifier, which has only 200 μA (typ) of supply current per amplifier.

The TLC226x, exhibiting high input impedance and low noise, are excellent for small-signal conditioning for high-impedance sources, such as piezoelectric transducers. Because of the micropower dissipation levels, these devices work well in hand-held monitoring and remote-sensing applications. In addition, the rail-to-rail output feature with single or split supplies makes this family a great choice when interfacing with analog-to-digital converters (ADCs). For precision applications, the TLC226xA family is available and has a maximum input offset voltage of 950 μV. This family is fully characterized at 5 V and ±5 V.

The TLC2262/4 also makes great upgrades to the TLC27M2/L4 or TS27M2/L4 in standard designs. They offer increased output dynamic range, lower noise voltage and lower input offset voltage. This enhanced feature set allows them to be used in a wider range of applications. For applications that require higher output drive and wider input voltage range, see the TLV2432 and TLV2442. If your design requires single amplifiers, please see the TLV2211/21/31 family. These devices are single rail-to-rail operational amplifiers in the SOT-23 package. Their small size and low power consumption, make them ideal for high density, battery-powered equipment.

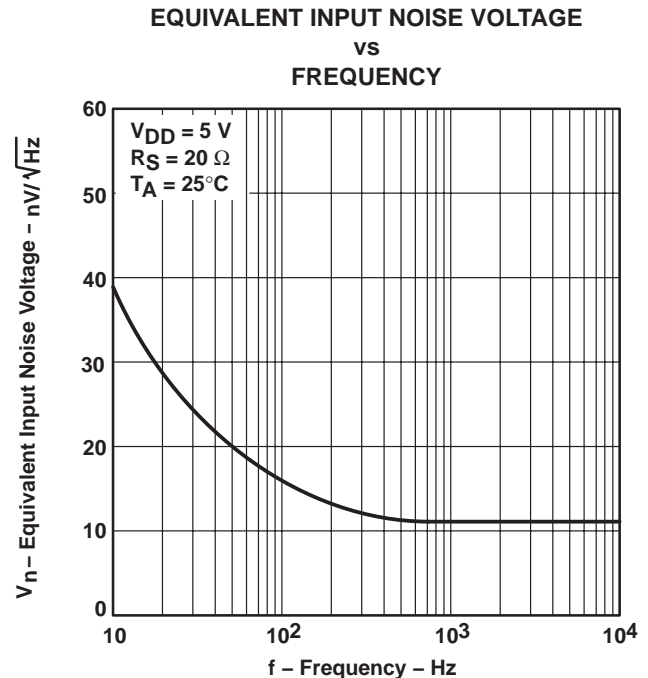


Figure 1



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

Advanced LinCMOS is a trademark of Texas Instruments.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.



POST OFFICE BOX 655303 • DALLAS, TEXAS 75265

Copyright © 2008 Texas Instruments Incorporated

# TLC226x-Q1, TLC226xA-Q1

## Advanced LinCMOS™ RAIL-TO-RAIL

### OPERATIONAL AMPLIFIERS

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

#### ORDERING INFORMATION†

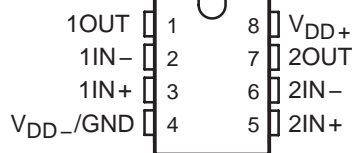
T <sub>A</sub>	V <sub>IO</sub> max AT 25°C	PACKAGE‡		ORDERABLE PART NUMBER	TOP-SIDE MARKING
-40°C to 125°C	950 μV	SOIC (D)	Tape and reel	TLC2262AQDRQ1§	2262AQ1
	2.5 mV	SOIC (D)	Tape and reel	TLC2262QDRQ1§	2262Q1
	950 μV	TSSOP (PW)	Tape and reel	TLC2262AQPWRQ1§	2262AQ1
	2.5 mV	TSSOP (PW)	Tape and reel	TLC2262QPWRQ1§	2262Q1
	950 μV	SOIC (D)	Tape and reel	TLC2264AQDRQ1	2264AQ1
	2.5 mV	SOIC (D)	Tape and reel	TLC2264QDRQ1	2264Q1
	950 μV	TSSOP (PW)	Tape and reel	TLC2264AQPWRQ1	2264AQ1
	2.5 mV	TSSOP (PW)	Tape and reel	TLC2264QPWRQ1	2264Q1

† For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at <http://www.ti.com>.

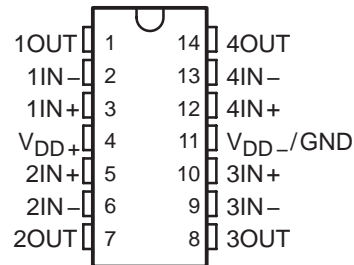
‡ Package drawings, thermal data, and symbolization are available at <http://www.ti.com/packaging>.

§ Product Preview.

**TLC2262, TLC2262A**  
**D OR PW PACKAGE**  
**(TOP VIEW)**



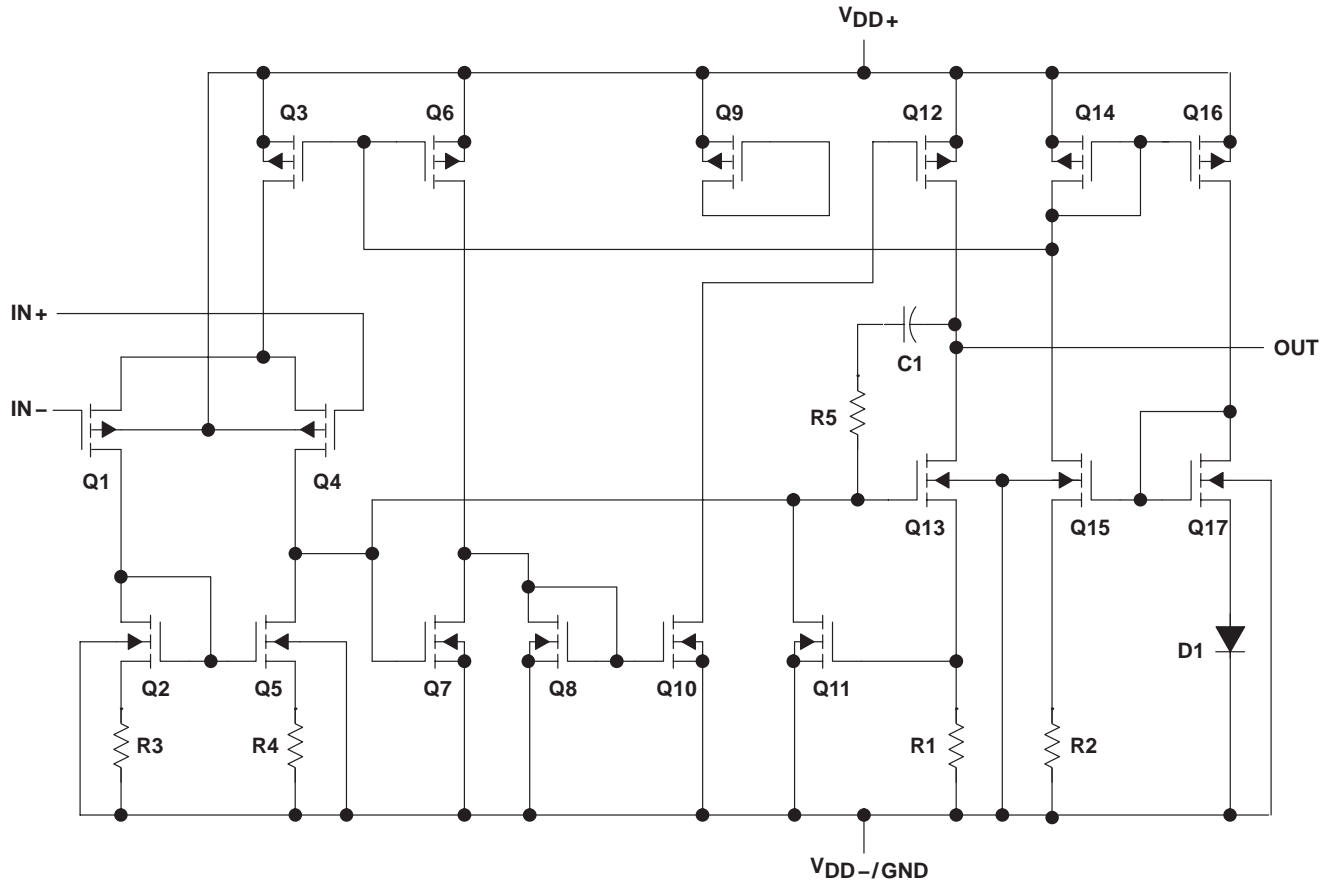
**TLC2264, TLC2264A**  
**D OR PW PACKAGE**  
**(TOP VIEW)**



# TLC226x-Q1, TLC226xA-Q1 Advanced LinCMOS™ RAIL-TO-RAIL OPERATIONAL AMPLIFIERS

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

equivalent schematic (each amplifier)



ACTUAL DEVICE COMPONENT COUNT†		
COMPONENT	TLC2262	TLC2264
Transistors	38	76
Resistors	28	56
Diodes	9	18
Capacitors	3	6

† Includes both amplifiers and all ESD, bias, and trim circuitry

# TLC226x-Q1, TLC226xA-Q1

## Advanced LinCMOS™ RAIL-TO-RAIL OPERATIONAL AMPLIFIERS

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

### absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, $V_{DD+}$ (see Note 1)	8 V
Supply voltage, $V_{DD-}$ (see Note 1)	-8 V
Differential input voltage, $V_{ID}$ (see Note 2)	±16 V
Input voltage, $V_I$ (any input, see Note 1)	$V_{DD-} - 0.3 \text{ V}$ to $V_{DD+}$
Input current, $I_I$ (each 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 (see Note 3)	unlimited
Continuous total dissipation	See Dissipation Rating Table
Operating free-air temperature range, $T_A$ : Q suffix	-40°C to 125°C
Storage temperature range, $T_{stg}$	-65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: D or PW package	260°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

- NOTES:
1. All voltage values, except differential voltages, are with respect to the midpoint between  $V_{DD+}$  and  $V_{DD-}$ .
  2. Differential voltages are at  $IN+$  with respect to  $IN-$ . Excessive current flows if input is brought below  $V_{DD-} - 0.3 \text{ V}$ .
  3. The output may be shorted to either supply. Temperature and/or supply voltages must be limited to ensure that the maximum dissipation rating is not exceeded.

DISSIPATION RATING TABLE

PACKAGE	$T_A \leq 25^\circ\text{C}$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25^\circ\text{C}$	$T_A = 70^\circ\text{C}$ POWER RATING	$T_A = 85^\circ\text{C}$ POWER RATING	$T_A = 125^\circ\text{C}$ POWER RATING
D-8	725 mW	5.8 mW/°C	464 mW	377 mW	145 mW
D-14	950 mW	7.6 mW/°C	608 mW	494 mW	190 mW
PW-14	750 mW	6.0 mW/°C	480 mW	389 mW	150 mW

### recommended operating conditions

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



**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TLC2262 electrical characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$  (unless otherwise noted)**

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC2262-Q1			TLC2262A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
$V_{IO}$ Input offset voltage	$V_{DD} \pm \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	25°C	300	2500		300	950	$\mu\text{V}$	
		Full range			3000		1500		
$\alpha_{VIO}$ Temperature coefficient of input offset voltage		Full range	5			5		$\mu\text{V}/^\circ\text{C}$	
Input offset voltage long-term drift (see Note 4)		25°C	0.003			0.003		$\mu\text{V}/\text{mo}$	
$I_{IO}$ Input offset current		25°C	0.5			0.5		$\text{pA}$	
		125°C		800		800			
$I_{IB}$ Input bias current		25°C	1			1		$\text{pA}$	
		125°C		800		800			
$V_{ICR}$ Common-mode input voltage range	$R_S = 50\ \Omega$ , $ V_{IO}  \leq 5\text{ mV}$	25°C	0 to 4	-0.3 to 4.2		0 to 4	-0.3 to 4.2	$\text{V}$	
		Full range	0 to 3.5			0 to 3.5			
$V_{OH}$ High-level output voltage	$I_{OH} = -20\ \mu\text{A}$	25°C		4.99			4.99	$\text{V}$	
		25°C	4.85	4.94		4.85	4.94		
		Full range	4.82			4.82			
		25°C	4.7	4.85		4.7	4.85		
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 50\ \mu\text{A}$	25°C		0.01			0.01	$\text{V}$	
		25°C	0.09	0.15		0.09	0.15		
		Full range		0.15			0.15		
		25°C	0.8	1		0.7	1		
$A_{VD}$ Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$ , $V_O = 1\text{ V to }4\text{ V}$	$R_L = 50\ \text{k}\Omega^\ddagger$	25°C	80	100		80	170	$\text{V}/\text{mV}$
			Full range	50			50		
		$R_L = 1\ \text{M}\Omega^\ddagger$	25°C		550			550	
			Full range		1.2			1.2	
$r_{i(d)}$ Differential input resistance		25°C		$10^{12}$			$10^{12}$	$\Omega$	
$r_{i(c)}$ Common-mode input resistance		25°C		$10^{12}$			$10^{12}$	$\Omega$	
$c_{i(c)}$ Common-mode input capacitance	$f = 10\ \text{kHz}$ , P package	25°C		8			8	$\text{pF}$	
$z_o$ Closed-loop output impedance	$f = 100\ \text{kHz}$ , $A_V = 10$	25°C		240			240	$\Omega$	
CMRR Common-mode rejection ratio	$V_{IC} = 0\text{ to }2.7\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 50\ \Omega$	25°C	70	83		70	83	$\text{dB}$	
		Full range	70			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	25°C	80	95		80	95	$\text{dB}$	
		Full range	80			80			
$I_{DD}$ Supply current	$V_O = 2.5\text{ V}$ , No load	25°C		400	500		400	500	$\mu\text{A}$
		Full range			500			500	

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix.

‡ Referenced to 2.5 V

NOTE 4: Typical values are based on the input offset voltage shift observed through 500 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.



**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TLC2262 operating characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$**

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC2262-Q1			TLC2262A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
SR	Slew rate at unity gain $V_O = 0.5\text{ V to }3.5\text{ V}, R_L = 50\text{ k}\Omega^\ddagger, C_L = 100\text{ pF}^\ddagger$	25°C	0.35	0.55		0.35	0.55	V/ $\mu\text{s}$	
		Full range	0.25			0.25			
$V_n$	Equivalent input noise voltage	f = 10 Hz		40			40	nV/ $\sqrt{\text{Hz}}$	
		f = 1 kHz		12			12		
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	f = 0.1 Hz to 1 Hz		0.7			0.7	$\mu\text{V}$	
		f = 0.1 Hz to 10 Hz		1.3			1.3		
$I_n$	Equivalent input noise current	25°C		0.6			0.6	fA/ $\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise $V_O = 0.5\text{ V to }2.5\text{ V}, f = 20\text{ kHz}, R_L = 50\text{ k}\Omega^\ddagger$	$A_V = 1$		0.017%			0.017%		
		$A_V = 10$		0.03%			0.03%		
	Gain-bandwidth product f = 50 kHz, $C_L = 100\text{ pF}^\ddagger$	$R_L = 50\text{ k}\Omega^\ddagger, 25^\circ\text{C}$		0.82			0.82	MHz	
BOM	Maximum output-swing bandwidth $V_O(PP) = 2\text{ V}, R_L = 50\text{ k}\Omega^\ddagger, A_V = 1, C_L = 100\text{ pF}^\ddagger$	25°C		185			185	kHz	
$t_s$	Settling time $A_V = -1, \text{ Step} = 0.5\text{ V to }2.5\text{ V}, R_L = 50\text{ k}\Omega^\ddagger, C_L = 100\text{ pF}^\ddagger$	To 0.1%		6.4			6.4	$\mu\text{s}$	
		To 0.01%		14.1			14.1		
$\phi_m$	Phase margin at unity gain $R_L = 50\text{ k}\Omega^\ddagger, C_L = 100\text{ pF}^\ddagger$	25°C		56°			56°		
		25°C		11			11		
	Gain margin	25°C		11			11	dB	

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix.

‡ Referenced to 2.5 V

**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TLC2262 electrical characteristics at specified free-air temperature,  $V_{DD\pm} = \pm 5\text{ V}$  (unless otherwise noted)**

PARAMETER	TEST CONDITIONS	T <sub>A</sub> †	TLC2262-Q1			TLC2262A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
V <sub>IO</sub> Input offset voltage	V <sub>IC</sub> = 0, V <sub>O</sub> = 0, R <sub>S</sub> = 50 Ω	25°C	300	2500		300	950	μV	
		Full range			3000		1500		
α <sub>VIO</sub> Temperature coefficient of input offset voltage		Full range		5			5	μV/°C	
Input offset voltage long-term drift (see Note 4)		25°C		0.003			0.003	μV/mo	
I <sub>IO</sub> Input offset current		25°C		0.5			0.5	pA	
		125°C			800		800		
I <sub>IB</sub> Input bias current	25°C		1			1	pA		
	125°C			800		800			
V <sub>ICR</sub> Common-mode input voltage range	R <sub>S</sub> = 50 Ω,  V <sub>IO</sub>   ≤ 5 mV	25°C	-5 to 4	-5.3 to 4		-5 to 4	-5.3 to 4.2	V	
		Full range			-5 to 3.5		-5 to 3.5		
V <sub>OM+</sub> Maximum positive peak output voltage	I <sub>O</sub> = -20 μA I <sub>O</sub> = -100 μA I <sub>O</sub> = -400 μA	25°C		4.99			4.99	V	
		25°C	4.85	4.94		4.85	4.94		
		Full range	4.82			4.82			
		25°C	4.7	4.85		4.7	4.85		
V <sub>OM-</sub> Maximum negative peak output voltage	V <sub>IC</sub> = 0, I <sub>O</sub> = 50 μA V <sub>IC</sub> = 0, I <sub>O</sub> = 500 μA V <sub>IC</sub> = 0, I <sub>O</sub> = 4 mA	25°C		-4.99			-4.99	V	
		25°C	-4.85	-4.91		-4.85	-4.91		
		Full range	-4.85			-4.85			
		25°C	-4	-4.3		-4	-4.3		
A <sub>VD</sub> Large-signal differential voltage amplification	V <sub>O</sub> = ±4 V	R <sub>L</sub> = 50 kΩ	25°C	80	200		80	200	V/mV
			Full range	50			50		
		R <sub>L</sub> = 1 MΩ	25°C		1000			1000	
r <sub>i(d)</sub> Differential input resistance		25°C		10 <sup>12</sup>			10 <sup>12</sup>	Ω	
r <sub>i(c)</sub> Common-mode input resistance		25°C		10 <sup>12</sup>			10 <sup>12</sup>	Ω	
c <sub>i(c)</sub> Common-mode input capacitance	f = 10 kHz, P package	25°C		8			8	pF	
z <sub>o</sub> Closed-loop output impedance	f = 100 kHz, A <sub>V</sub> = 10	25°C		220			220	Ω	
CMRR Common-mode rejection ratio	V <sub>IC</sub> = -5 V to 2.7 V, V <sub>O</sub> = 0, R <sub>S</sub> = 50 Ω	25°C	75	88		75	88	dB	
		Full range	75			75			
k <sub>SVR</sub> Supply-voltage rejection ratio (ΔV <sub>DD±</sub> /ΔV <sub>IO</sub> )	V <sub>DD</sub> = 4.4 V to 16 V, V <sub>IC</sub> = V <sub>DD</sub> /2, No load	25°C	80	95		80	95	dB	
		Full range	80			80			
I <sub>DD</sub> Supply current	V <sub>O</sub> = 0, No load	25°C		425	500		425	500	μA
		Full range			500			500	

† Full range is -40°C to 125°C for Q suffix.

NOTE 4: Typical values are based on the input offset voltage shift observed through 500 hours of operating life test at T<sub>A</sub> = 150°C extrapolated to T<sub>A</sub> = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.



**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TLC2262 operating characteristics at specified free-air temperature,  $V_{DD\pm} = \pm 5\text{ V}$**

PARAMETER	TEST CONDITIONS		$T_A$ †	TLC2262-Q1			TLC2262A-Q1			UNIT	
				MIN	TYP	MAX	MIN	TYP	MAX		
SR	Slew rate at unity gain	$V_O = \pm 2\text{ V}$ , $C_L = 100\text{ pF}$	$R_L = 50\text{ k}\Omega$	25°C	0.35	0.55		0.35	0.55	V/ $\mu\text{s}$	
				Full range	0.25		0.25				
$V_n$	Equivalent input noise voltage			25°C	43			43			nV/ $\sqrt{\text{Hz}}$
				25°C	12			12			
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage			25°C	0.8			0.8			$\mu\text{V}$
				25°C	1.3			1.3			
$I_n$	Equivalent input noise current			25°C	0.6			0.6			fA/ $\sqrt{\text{Hz}}$
THD + N	Total harmonic distortion plus noise	$V_O = \pm 2.3\text{ V}$ , $R_L = 50\text{ k}\Omega$ , $f = 20\text{ kHz}$		25°C	$A_V = 1$			0.014%			
					$A_V = 10$			0.024%			
	Gain-bandwidth product	$f = 10\text{ kHz}$ , $C_L = 100\text{ pF}$	$R_L = 50\text{ k}\Omega$	25°C	0.73			0.73			MHz
BOM	Maximum output-swing bandwidth	$V_{O(PP)} = 4.6\text{ V}$ , $R_L = 50\text{ k}\Omega$ ,	$A_V = 1$ , $C_L = 100\text{ pF}$	25°C	85			85			kHz
$t_s$	Settling time	$A_V = -1$ , Step = $-2.3\text{ V}$ to $2.3\text{ V}$ , $R_L = 50\text{ k}\Omega$ , $C_L = 100\text{ pF}$	To 0.1%	25°C	7.1			7.1			$\mu\text{s}$
			To 0.01%		16.5			16.5			
$\phi_m$	Phase margin at unity gain	$R_L = 50\text{ k}\Omega$ ,	$C_L = 100\text{ pF}$	25°C	57°			57°			
	Gain margin			25°C	11			11			

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix.



**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TLC2264 electrical characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$  (unless otherwise noted)**

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC2264-Q1			TLC2264A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
$V_{IO}$ Input offset voltage		25°C		300	2500		300	950	$\mu\text{V}$
		Full range			3000			1500	
$\alpha_{VIO}$ Temperature coefficient of input offset voltage		Full range		2			2	$\mu\text{V}/^\circ\text{C}$	
Input offset voltage long-term drift (see Note 4)	$V_{DD\pm} = \pm 2.5\text{ V}$ , $V_O = 0$ , $V_{IC} = 0$ , $R_S = 50\ \Omega$	25°C		0.003			0.003	$\mu\text{V}/\text{mo}$	
$I_{IO}$ Input offset current		25°C		0.5			0.5	$\text{pA}$	
		125°C			800		800		
$I_{IB}$ Input bias current		25°C		1			1	$\text{pA}$	
		125°C			800		800		
$V_{ICR}$ Common-mode input voltage range		$R_S = 50\ \Omega$ , $ V_{IO}  \leq 5\text{ mV}$	25°C	0 to 4	-0.3 to 4.2		0 to 4	-0.3 to 4.2	V
	Full range		0 to 3.5			0 to 3.5			
$V_{OH}$ High-level output voltage	$I_{OH} = -20\ \mu\text{A}$	25°C		4.99			4.99	V	
		25°C	4.85	4.94		4.85	4.94		
		Full range	4.82			4.82			
		25°C	4.7	4.85		4.7	4.85		
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 50\ \mu\text{A}$	25°C		0.01			0.01	V	
		25°C	0.09	0.15		0.09	0.15		
		Full range		0.15			0.15		
		25°C	0.8	1		0.7	1		
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 500\ \mu\text{A}$	25°C		0.01			0.01	V	
		25°C	0.09	0.15		0.09	0.15		
		Full range		0.15			0.15		
		25°C	0.8	1		0.7	1		
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 4\text{ mA}$	25°C		0.01			0.01	V	
		25°C	0.09	0.15		0.09	0.15		
		Full range		0.15			0.15		
		25°C	0.8	1		0.7	1		
$A_{VD}$ Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$ , $V_O = 1\text{ V to }4\text{ V}$	$R_L = 50\text{ k}\Omega$ ‡	25°C	80	100		80	170	V/mV
			Full range	50			50		
			25°C		550			550	
$A_{VD}$ Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$ , $V_O = 1\text{ V to }4\text{ V}$	$R_L = 1\text{ M}\Omega$ ‡	25°C		550			550	V/mV
			Full range						
			25°C		550			550	
$r_{i(d)}$ Differential input resistance		25°C		$10^{12}$			$10^{12}$	$\Omega$	
$r_{i(c)}$ Common-mode input resistance		25°C		$10^{12}$			$10^{12}$	$\Omega$	
$c_{i(c)}$ Common-mode input capacitance	$f = 10\text{ kHz}$ , N package	25°C		8			8	pF	
$z_o$ Closed-loop output impedance	$f = 100\text{ kHz}$ , $A_V = 10$	25°C		240			240	$\Omega$	
CMRR Common-mode rejection ratio	$V_{IC} = 0\text{ to }2.7\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 50\ \Omega$	25°C	70	83		70	83	dB	
		Full range	70			70			
$k_{SVR}$ Supply-voltage rejection ratio ( $\Delta V_{DD}/\Delta V_{IO}$ )	$V_{DD} = 4.4\text{ V to }16\text{ V}$ ,	25°C	80	95		80	95	dB	
$I_{DD}$ Supply current (four amplifiers)	$V_O = 2.5\text{ V}$ , No load	25°C		0.8	1		0.8	1	mA
		Full range			1			1	

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix.

‡ Referenced to 2.5 V

NOTE 4: Typical values are based on the input offset voltage shift observed through 500 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.



**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TLC2264 operating characteristics at specified free-air temperature,  $V_{DD} = 5\text{ V}$**

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC2264-Q1			TLC2264A-Q1			UNIT	
			MIN	TYP	MAX	MIN	TYP	MAX		
SR	Slew rate at unity gain $V_O = 0.5\text{ V to }3.5\text{ V}, R_L = 50\text{ k}\Omega^\ddagger, C_L = 100\text{ pF}^\ddagger$	25°C	0.35	0.55		0.35	0.55	V/ $\mu\text{s}$		
		Full range	0.25			0.25				
$V_n$	Equivalent input noise voltage	f = 10 Hz	40			40			nV/ $\sqrt{\text{Hz}}$	
		f = 1 kHz	12			12				
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	f = 0.1 Hz to 1 Hz	0.7			0.7			$\mu\text{V}$	
		f = 0.1 Hz to 10 Hz	1.3			1.3				
$I_n$	Equivalent input noise current	25°C	0.6			0.6			fA/ $\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise $V_O = 0.5\text{ V to }2.5\text{ V}, f = 20\text{ kHz}, R_L = 50\text{ k}\Omega^\ddagger$	$A_V = 1$	0.017%			0.017%				
		$A_V = 10$	0.03%			0.03%				
	Gain-bandwidth product	f = 50 kHz, $R_L = 50\text{ k}\Omega^\ddagger, C_L = 100\text{ pF}^\ddagger$	0.71			0.71			MHz	
BOM	Maximum output-swing bandwidth	$V_{O(PP)} = 2\text{ V}, R_L = 50\text{ k}\Omega^\ddagger, A_V = 1, C_L = 100\text{ pF}^\ddagger$	185			185			kHz	
$t_s$	Settling time	$A_V = -1, \text{ Step} = 0.5\text{ V to }2.5\text{ V}, R_L = 50\text{ k}\Omega^\ddagger, C_L = 100\text{ pF}^\ddagger$	To 0.1%	6.4			6.4			$\mu\text{s}$
			To 0.01%	14.1			14.1			
$\phi_m$	Phase margin at unity gain	$R_L = 50\text{ k}\Omega^\ddagger, C_L = 100\text{ pF}^\ddagger$	56°			56°				
	Gain margin		11			11				dB

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix.

‡ Referenced to 2.5 V



**TLC2264 electrical characteristics at specified free-air temperature,  $V_{DD\pm} = \pm 5\text{ V}$  (unless otherwise noted)**

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC2264-Q1			TLC2264A-Q1			UNIT	
			MIN	TYP	MAX	MIN	TYP	MAX		
$V_{IO}$ Input offset voltage		25°C	300	2500		300	950	$\mu\text{V}$		
		Full range			3000		1500			
$\alpha_{VIO}$ Temperature coefficient of input offset voltage		Full range	2			2			$\mu\text{V}/^\circ\text{C}$	
Input offset voltage long-term drift (see Note 4)	$V_{IC} = 0,$ $R_S = 50\ \Omega$	$V_O = 0,$	25°C			0.003			$\mu\text{V}/\text{mo}$	
$I_{IO}$ Input offset current			25°C	0.5			0.5			$\text{pA}$
$I_{IB}$ Input bias current		125°C	800			800				
		25°C	1			1			$\text{pA}$	
	125°C	800			800					
$V_{ICR}$ Common-mode input voltage range	$R_S = 50\ \Omega,$ $ V_{IO}  \leq 5\ \text{mV}$	25°C	-5 to 4	-5.3 to 4.2		-5 to 4	-5.3 to 4.2	V		
		Full range	-5 to 3.5			-5 to 3.5				
$V_{OM+}$ Maximum positive peak output voltage	$I_O = -20\ \mu\text{A}$	25°C	4.99			4.99			V	
		25°C	4.85	4.94		4.85	4.94			
		Full range	4.82			4.82				
		25°C	4.7	4.85		4.7	4.85			
$V_{OM-}$ Maximum negative peak output voltage	$I_O = -400\ \mu\text{A}$	25°C	-4.99			-4.99			V	
		25°C	-4.85	-4.91		-4.85	-4.91			
		Full range	-4.85			-4.85				
		25°C	-4	-4.3		-4	-4.3			
$A_{VD}$ Large-signal differential voltage amplification	$V_O = \pm 4\ \text{V}$	$R_L = 50\ \text{k}\Omega$	25°C	80	200		80	200		V/mV
			Full range	50			50			
		$R_L = 1\ \text{M}\Omega$	25°C	1000			1000			
			Full range	-3.8			-3.8			
$r_{i(d)}$ Differential input resistance		25°C	$10^{12}$			$10^{12}$			$\Omega$	
$r_{i(c)}$ Common-mode input resistance		25°C	$10^{12}$			$10^{12}$			$\Omega$	
$c_{i(c)}$ Common-mode input capacitance	$f = 10\ \text{kHz},$	N package	25°C	8			8			$\text{pF}$
$z_o$ Closed-loop output impedance	$f = 100\ \text{kHz},$	$A_V = 10$	25°C	220			220			$\Omega$
CMRR Common-mode rejection ratio	$V_{IC} = -5\ \text{V to } 2.7\ \text{V},$ $V_O = 0,$	$R_S = 50\ \Omega$	25°C	75	88		75	88		dB
			Full range	75			75			
$k_{SVR}$ Supply-voltage rejection ratio ( $\Delta V_{DD\pm}/\Delta V_{IO}$ )	$V_{DD\pm} = \pm 2.2\ \text{V to } \pm 8\ \text{V},$ $V_{IC} = V_{DD}/2,$	No load	25°C	80	95		80	95		dB
			Full range	80			80			
$I_{DD}$ Supply current (four amplifiers)	$V_O = 0,$	No load	25°C	0.85	1		0.85	1		mA
			Full range	1			1			

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix.

NOTE 4: Typical values are based on the input offset voltage shift observed through 500 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.

**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TLC2264 operating characteristics at specified free-air temperature,  $V_{DD\pm} = \pm 5\text{ V}$**

PARAMETER	TEST CONDITIONS	$T_A$ †	TLC2264-Q1			TLC2264A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
SR	Slew rate at unity gain $V_O = \pm 2\text{ V}$ , $C_L = 100\text{ pF}$ $R_L = 50\text{ k}\Omega$	25°C	0.35	0.55		0.35	0.55	V/ $\mu$ s	
		Full range	0.25			0.25			
$V_n$	Equivalent input noise voltage $f = 10\text{ Hz}$ $f = 1\text{ kHz}$	25°C		43			43	nV/ $\sqrt{\text{Hz}}$	
		25°C		12			12		
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage $f = 0.1\text{ Hz to }1\text{ Hz}$ $f = 0.1\text{ Hz to }10\text{ Hz}$	25°C		0.8			0.8	$\mu$ V	
		25°C		1.3			1.3		
$I_n$	Equivalent input noise current	25°C		0.6			0.6	fA/ $\sqrt{\text{Hz}}$	
THD + N	Total harmonic distortion plus noise $V_O = \pm 2.3\text{ V}$ , $R_L = 50\text{ k}\Omega$ , $f = 20\text{ kHz}$	$A_V = 1$		0.014%			0.014%		
		$A_V = 10$		0.024%			0.024%		
	Gain-bandwidth product $f = 10\text{ kHz}$ , $C_L = 100\text{ pF}$ $R_L = 50\text{ k}\Omega$	25°C		0.73			0.73	MHz	
BOM	Maximum output-swing bandwidth $V_{O(PP)} = 4.6\text{ V}$ , $R_L = 50\text{ k}\Omega$	$A_V = 1$ , $C_L = 100\text{ pF}$	25°C		70			70	kHz
$t_s$	Settling time $A_V = -1$ , Step = $-2.3\text{ V to }2.3\text{ V}$ , $R_L = 50\text{ k}\Omega$ , $C_L = 100\text{ pF}$	To 0.1%	25°C		7.1			7.1	$\mu$ s
		To 0.01%			16.5			16.5	
$\phi_m$	Phase margin at unity gain $R_L = 50\text{ k}\Omega$ , $C_L = 100\text{ pF}$	25°C		57°			57°		
		25°C		11			11		dB

† Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$  for Q suffix.



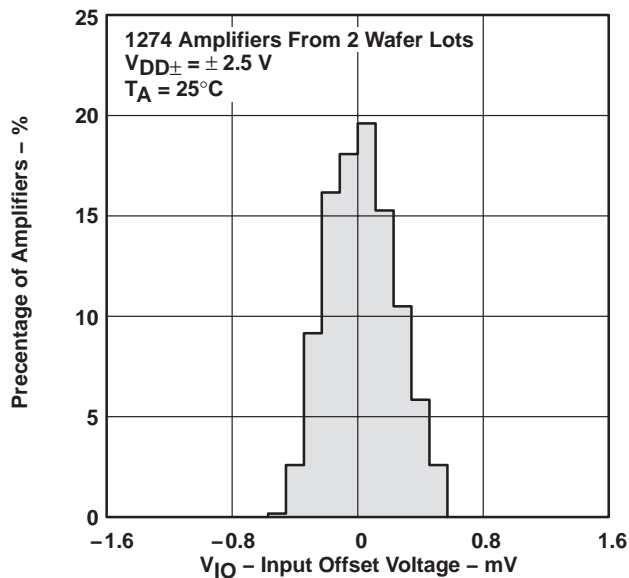
## TYPICAL CHARACTERISTICS

**Table of Graphs**

		FIGURE	
$V_{IO}$	Input offset voltage	Distribution vs Common-mode input voltage	2 – 5 6, 7
$\alpha_{VIO}$	Input offset voltage temperature coefficient	Distribution	8 – 11
$I_{IB}/I_{IO}$	Input bias and input offset currents	vs Free-air temperature	12
$V_I$	Input voltage range	vs Supply voltage vs Free-air temperature	13 14
$V_{OH}$	High-level output voltage	vs High-level output current	15
$V_{OL}$	Low-level output voltage	vs Low-level output current	16, 17
$V_{OM+}$	Maximum positive output voltage	vs Output current	18
$V_{OM-}$	Maximum negative output voltage	vs Output current	19
$V_{O(PP)}$	Maximum peak-to-peak output voltage	vs Frequency	20
$I_{OS}$	Short-circuit output current	vs Supply voltage vs Free-air temperature	21 22
$V_O$	Output voltage	vs Differential input voltage	23, 24
	Differential gain	vs Load resistance	25
$A_{VD}$	Large-signal differential voltage amplification	vs Frequency vs Free-air temperature	26, 27 28, 29
$z_o$	Output impedance	vs Frequency	30, 31
$CMRR$	Common-mode rejection ratio	vs Frequency vs Free-air temperature	32 33
$k_{SVR}$	Supply-voltage rejection ratio	vs Frequency vs Free-air temperature	34, 35 36
$I_{DD}$	Supply current	vs Supply voltage vs Free-air temperature	37, 38 39, 40
$SR$	Slew rate	vs Load capacitance vs Free-air temperature	41 42
$V_O$	Inverting large-signal pulse response		43, 44
	Voltage-follower large-signal pulse response		45, 46
	Inverting small-signal pulse response		47, 48
	Voltage-follower small-signal pulse response		49, 50
$V_n$	Equivalent input noise voltage	vs Frequency	51, 52
	Noise voltage (referred to input)	Over a 10-second period	53
	Integrated noise voltage	vs Frequency	54
$THD + N$	Total harmonic distortion plus noise	vs Frequency	55
	Gain-bandwidth product	vs Supply voltage vs Free-air temperature	56 57
$\phi_m$	Phase margin	vs Frequency vs Load capacitance	26, 27 58
	Gain margin	vs Load capacitance	59
$B_1$	Unity-gain bandwidth	vs Load capacitance	60
	Overestimation of phase margin	vs Load capacitance	61

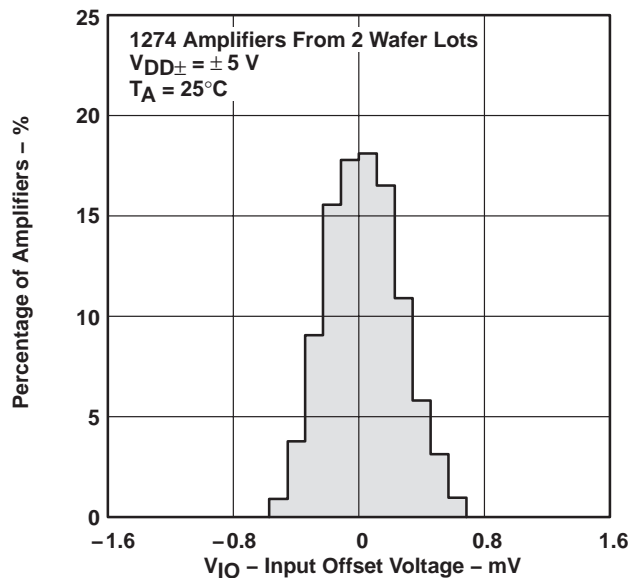
**TYPICAL CHARACTERISTICS**

**DISTRIBUTION OF TLC2262  
 INPUT OFFSET VOLTAGE**



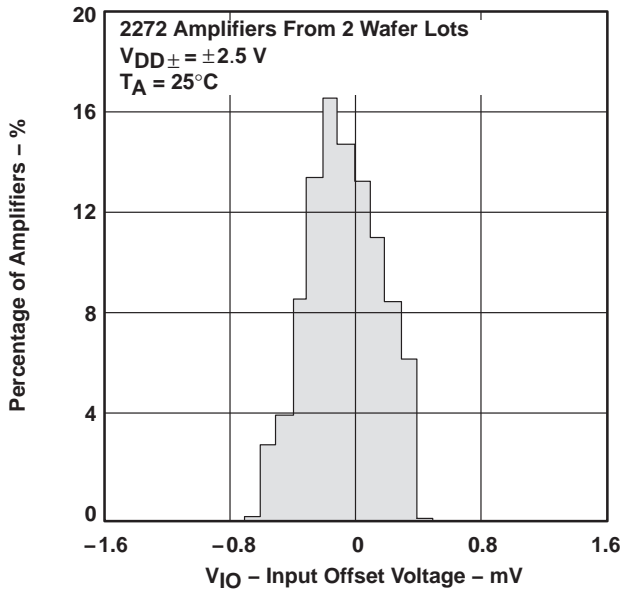
**Figure 2**

**DISTRIBUTION OF TLC2262  
 INPUT OFFSET VOLTAGE**



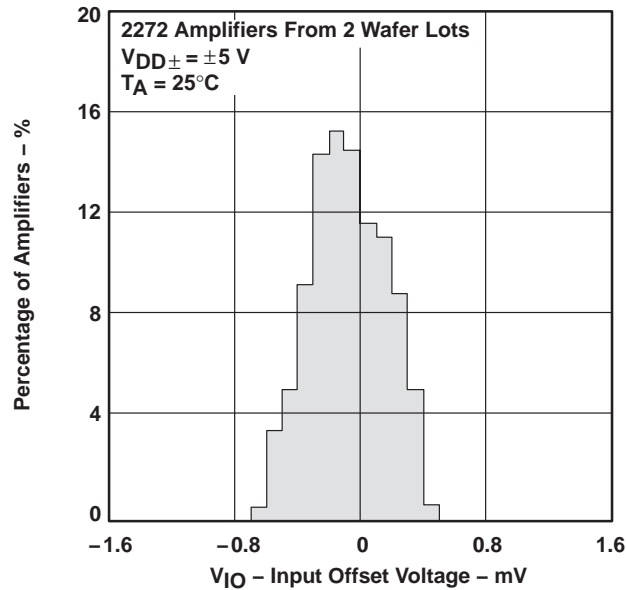
**Figure 3**

**DISTRIBUTION OF TLC2264  
 INPUT OFFSET VOLTAGE**



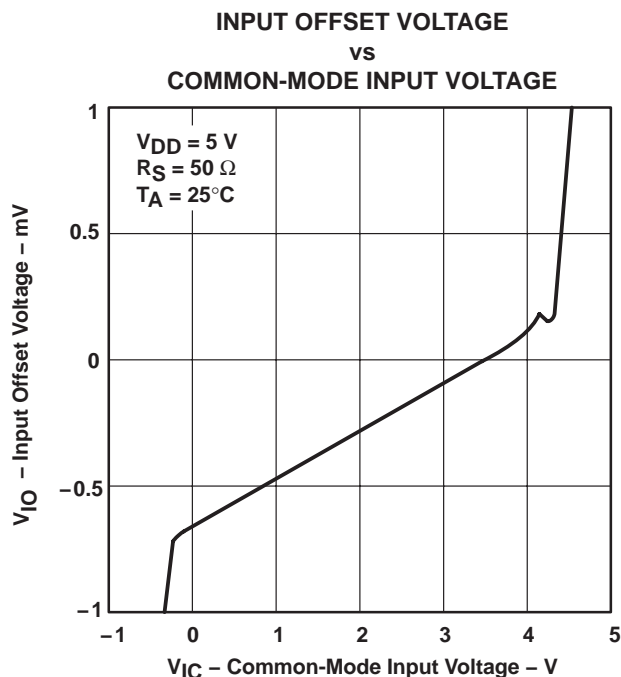
**Figure 4**

**DISTRIBUTION OF TLC2264  
 INPUT OFFSET VOLTAGE**



**Figure 5**

TYPICAL CHARACTERISTICS



† For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.

Figure 6

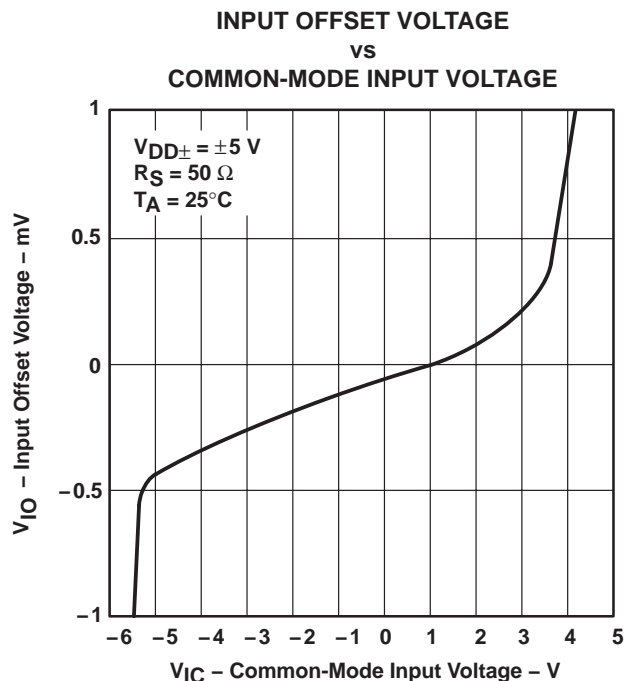


Figure 7

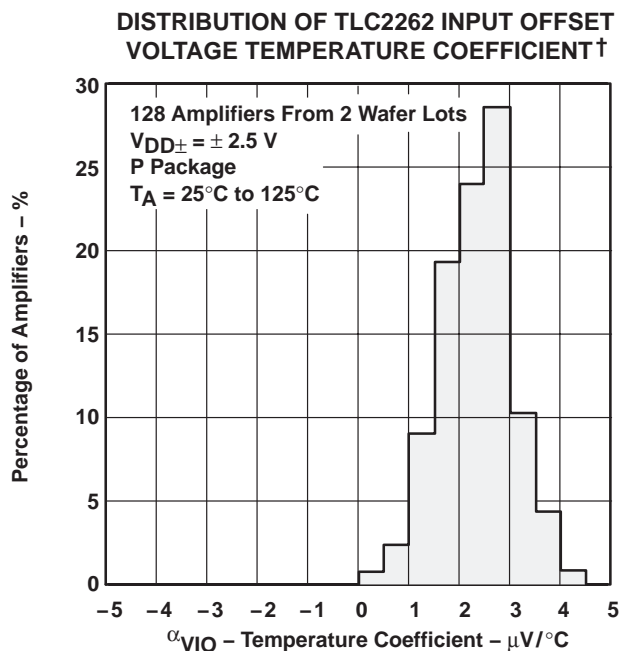


Figure 8

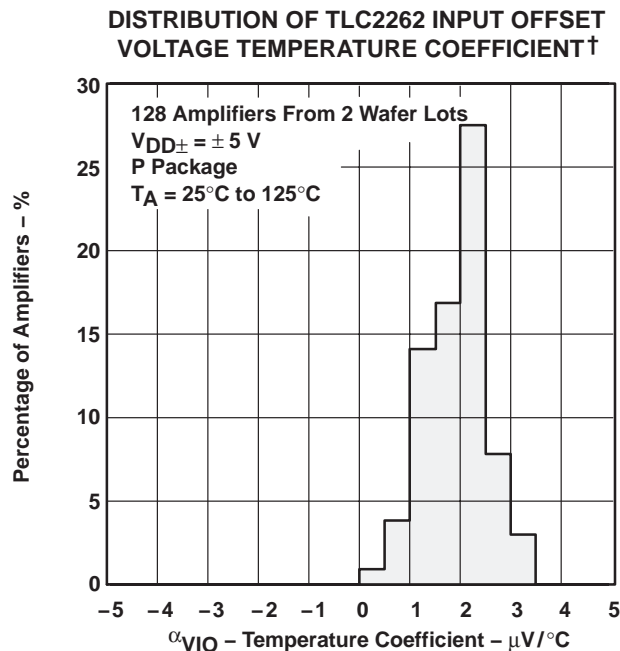
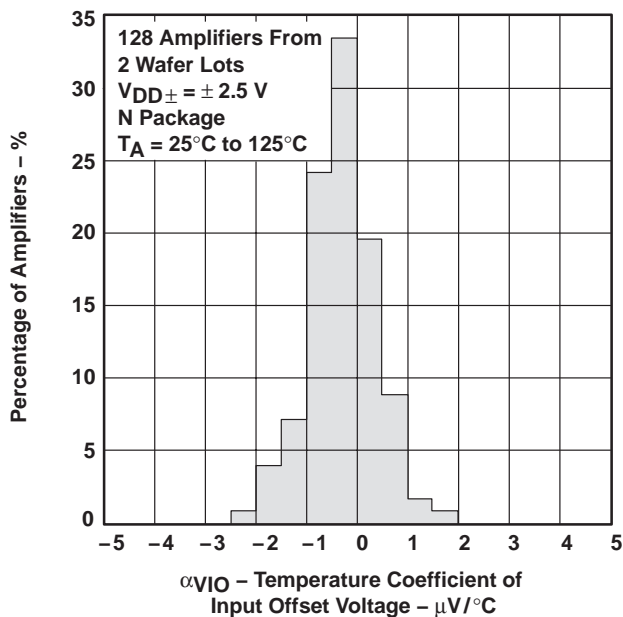


Figure 9

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

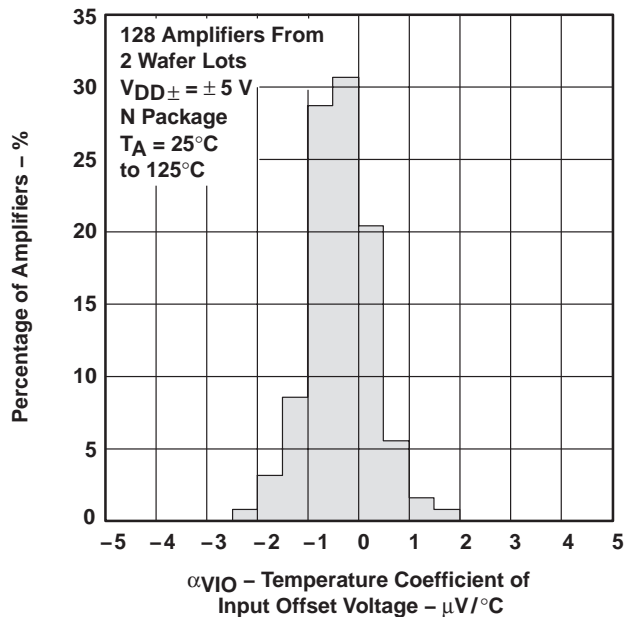
**TYPICAL CHARACTERISTICS**

**DISTRIBUTION OF TLC2264 INPUT OFFSET VOLTAGE TEMPERATURE COEFFICIENT†**



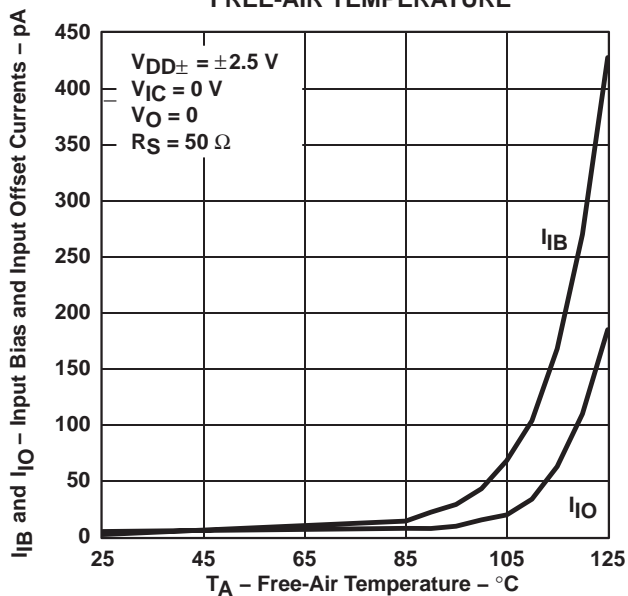
**Figure 10**

**DISTRIBUTION OF TLC2264 INPUT OFFSET VOLTAGE TEMPERATURE COEFFICIENT†**



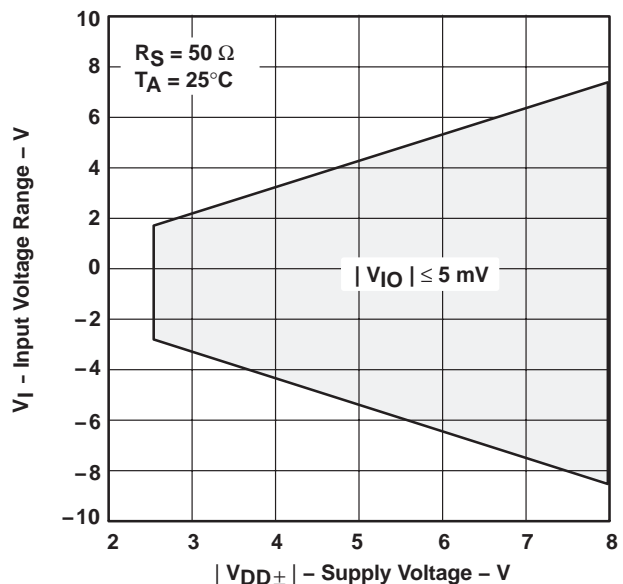
**Figure 11**

**INPUT BIAS AND INPUT OFFSET CURRENTS†**  
**vs**  
**FREE-AIR TEMPERATURE**



**Figure 12**

**INPUT VOLTAGE RANGE**  
**vs**  
**SUPPLY VOLTAGE**



**Figure 13**

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



TYPICAL CHARACTERISTICS

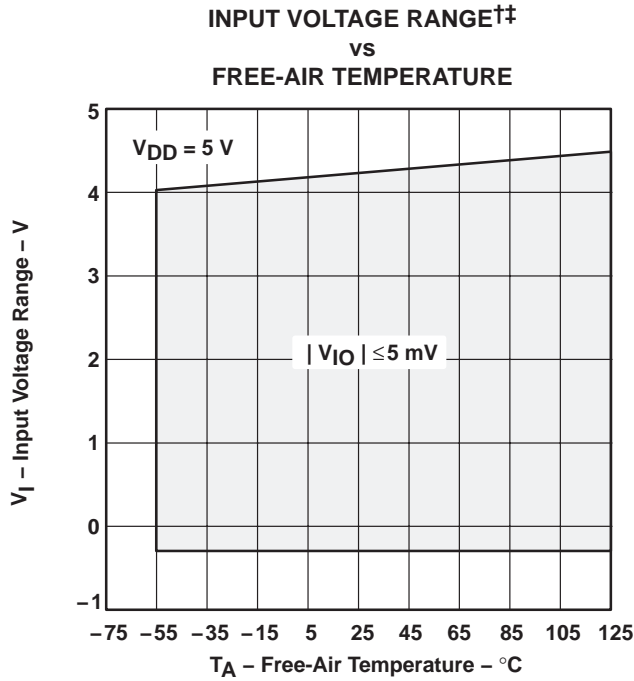


Figure 14

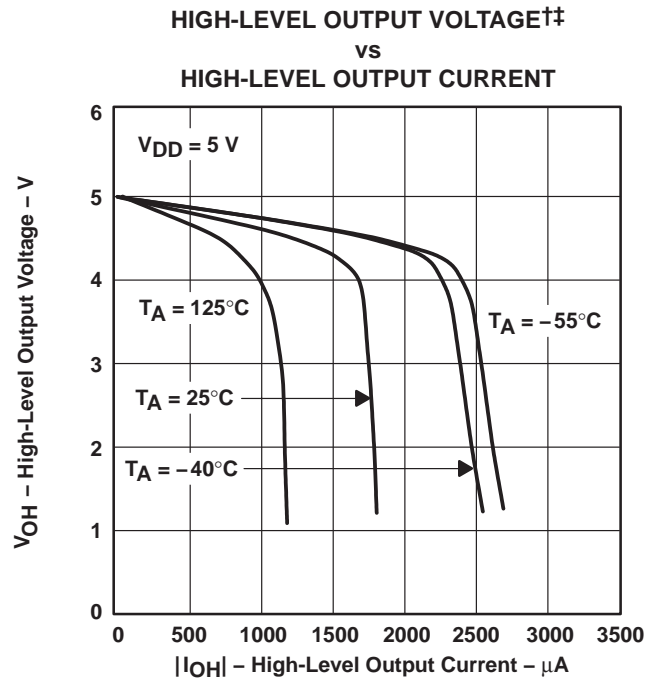


Figure 15

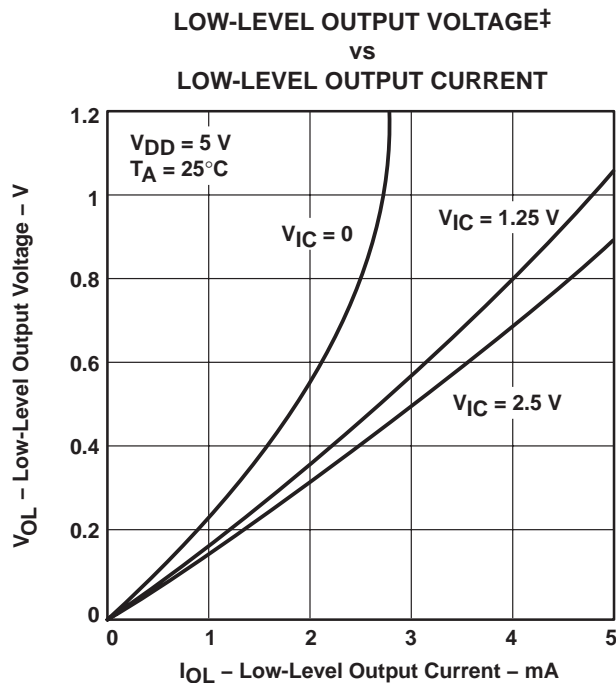


Figure 16

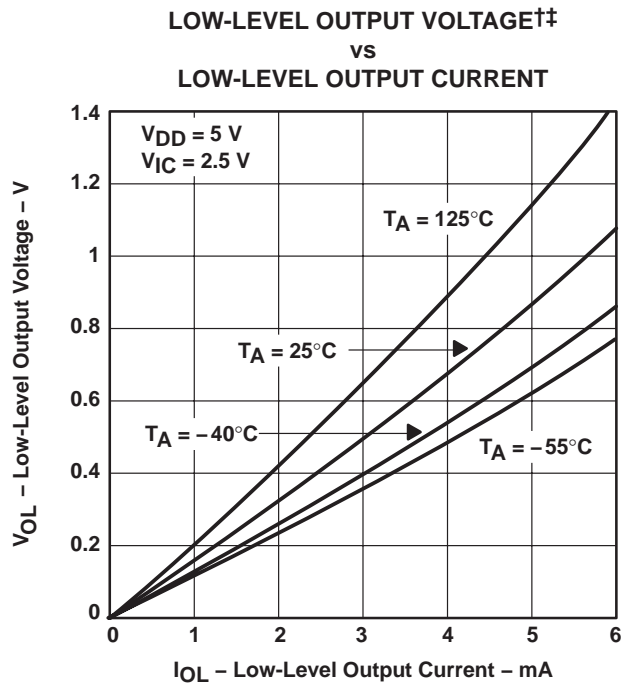


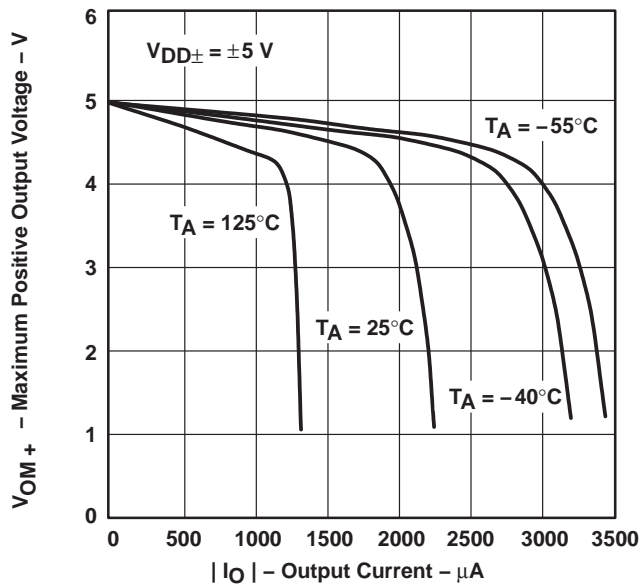
Figure 17

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

†† For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.

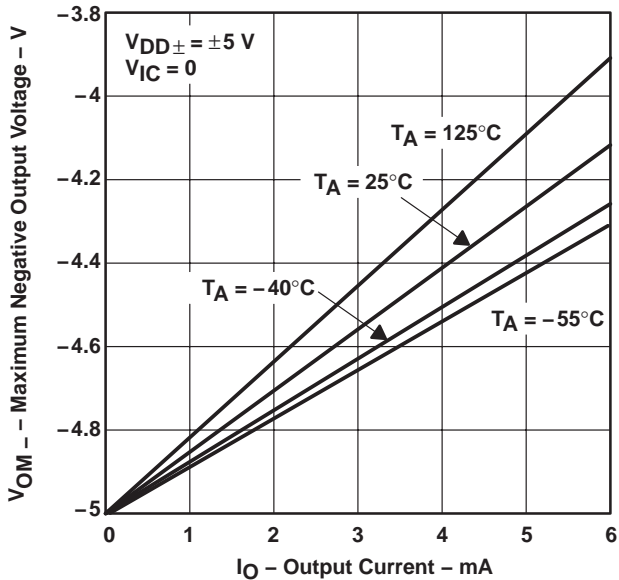
**TYPICAL CHARACTERISTICS**

**MAXIMUM POSITIVE OUTPUT VOLTAGE†**  
**vs**  
**OUTPUT CURRENT**



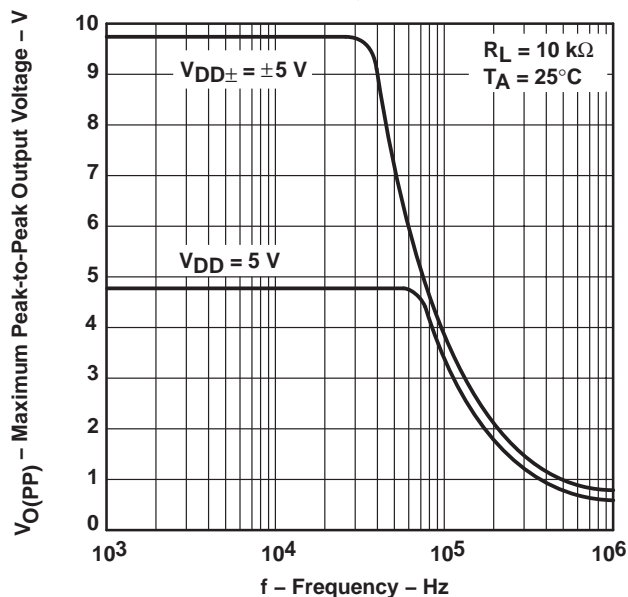
**Figure 18**

**MAXIMUM NEGATIVE OUTPUT VOLTAGE†**  
**vs**  
**OUTPUT CURRENT**



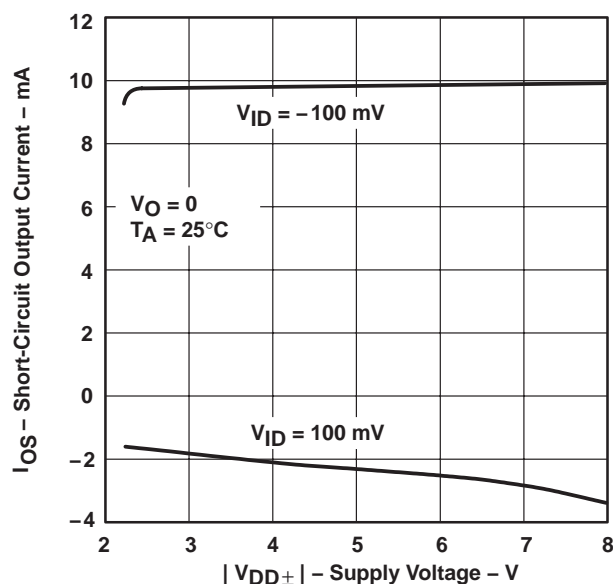
**Figure 19**

**MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE†‡**  
**vs**  
**FREQUENCY**



**Figure 20**

**SHORT-CIRCUIT OUTPUT CURRENT**  
**vs**  
**SUPPLY VOLTAGE**



**Figure 21**

‡ For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.

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

TYPICAL CHARACTERISTICS

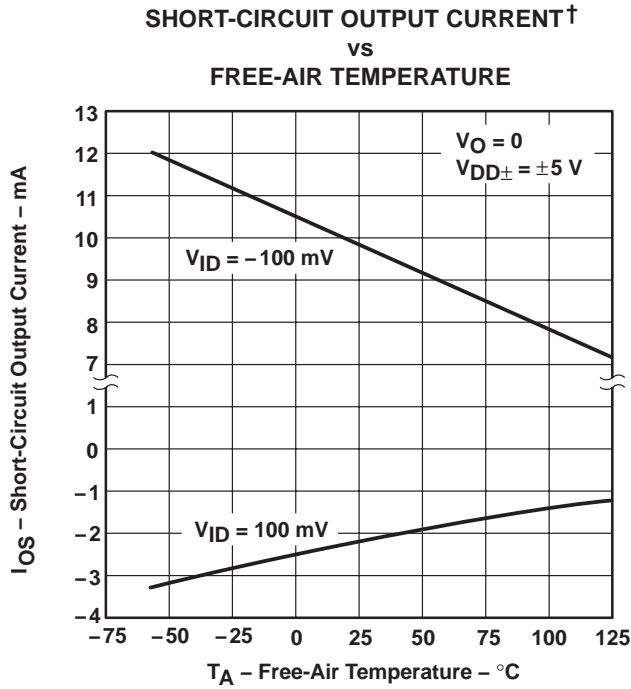


Figure 22

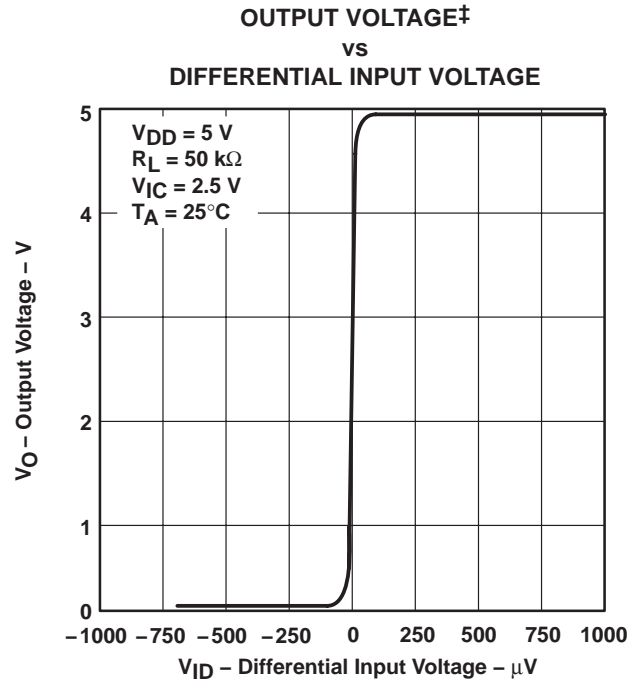


Figure 23

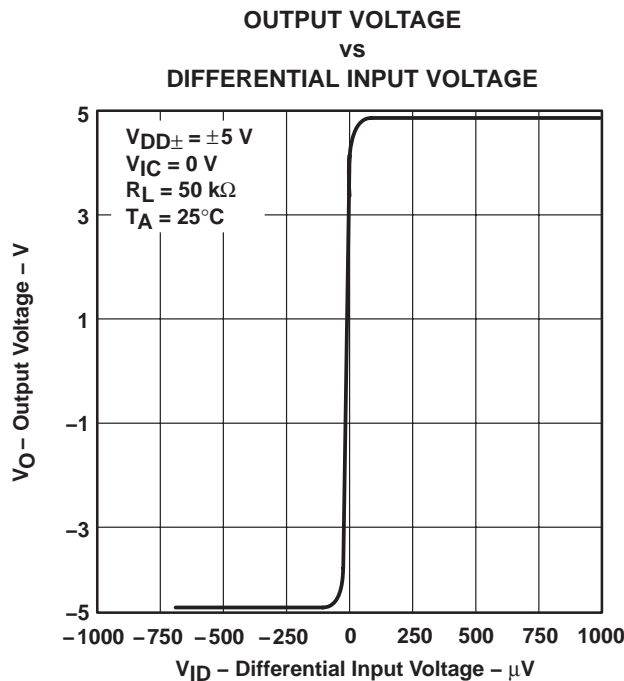


Figure 24

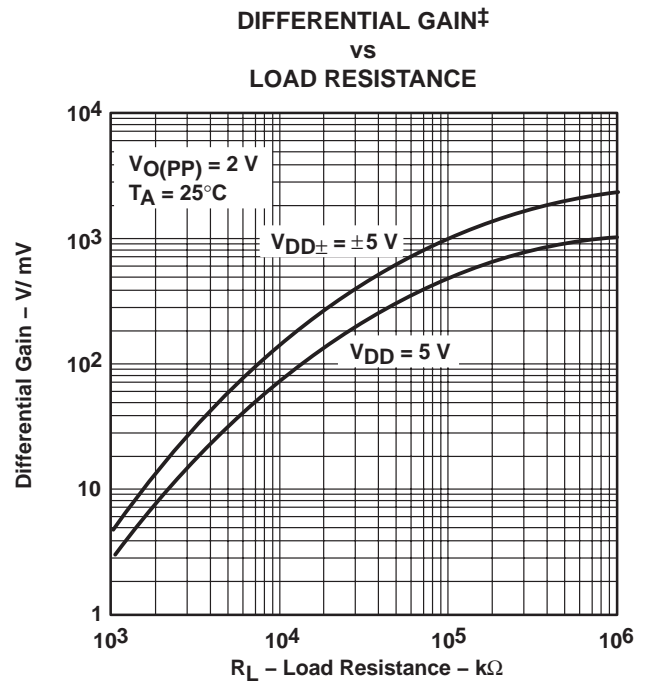


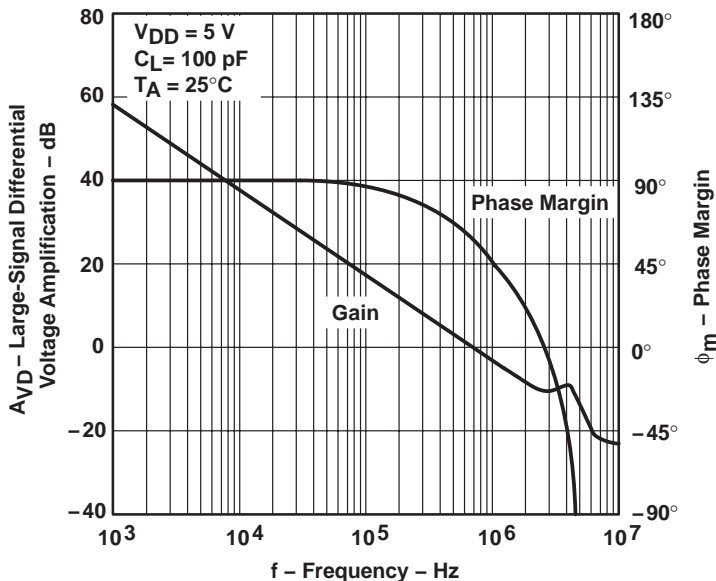
Figure 25

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

‡ For curves where  $V_{DD} = 5 \text{ V}$ , all loads are referenced to 2.5 V.

**TYPICAL CHARACTERISTICS**

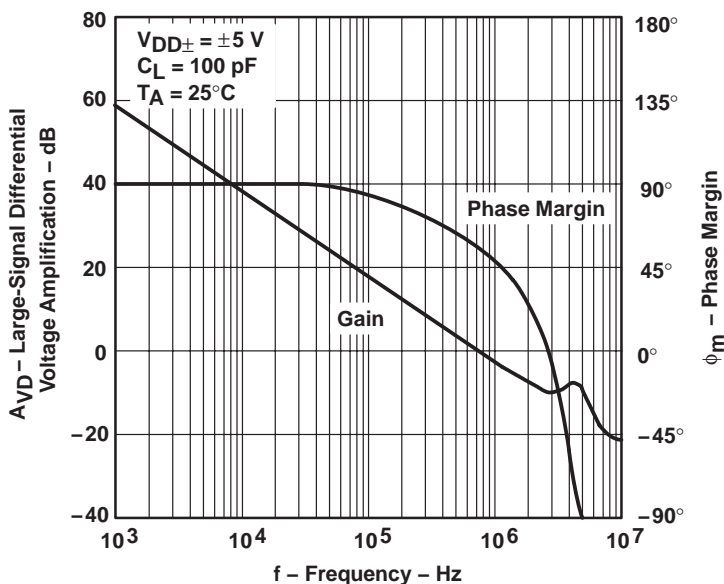
**LARGE-SIGNAL DIFFERENTIAL VOLTAGE†  
 AMPLIFICATION AND PHASE MARGIN  
 vs  
 FREQUENCY**



† For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.

**Figure 26**

**LARGE-SIGNAL DIFFERENTIAL VOLTAGE  
 AMPLIFICATION AND PHASE MARGIN  
 vs  
 FREQUENCY**



**Figure 27**

TYPICAL CHARACTERISTICS

LARGE-SIGNAL DIFFERENTIAL  
VOLTAGE AMPLIFICATION†‡  
vs  
FREE-AIR TEMPERATURE

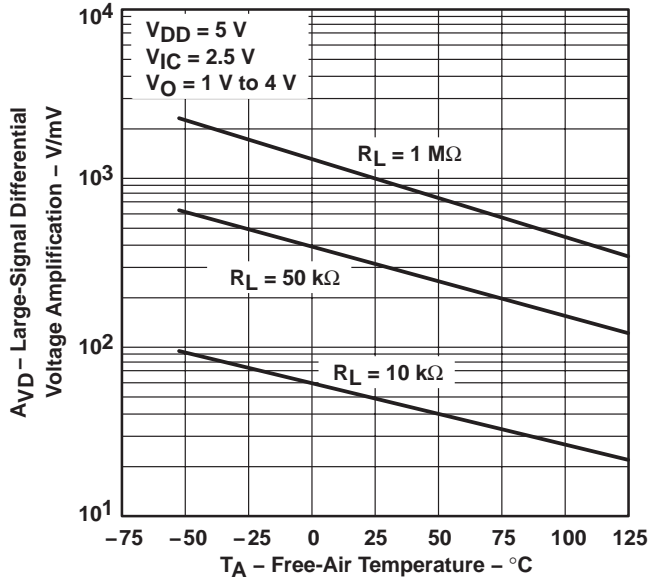


Figure 28

LARGE-SIGNAL DIFFERENTIAL  
VOLTAGE AMPLIFICATION†  
vs  
FREE-AIR TEMPERATURE

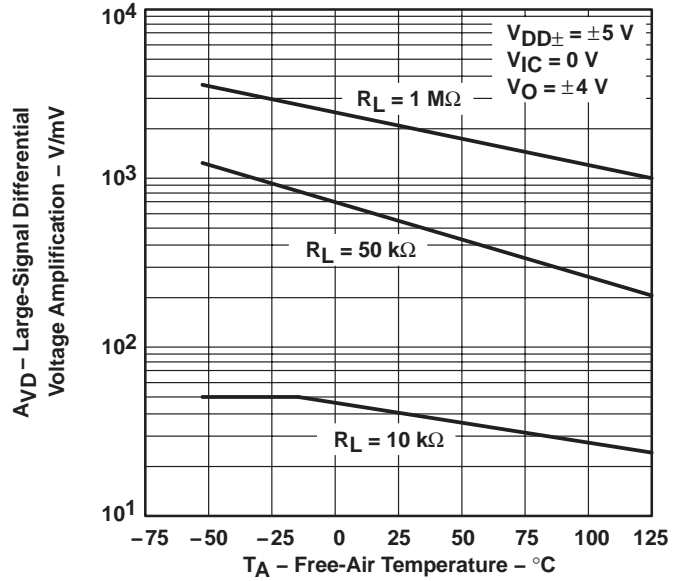


Figure 29

OUTPUT IMPEDANCE‡  
vs  
FREQUENCY

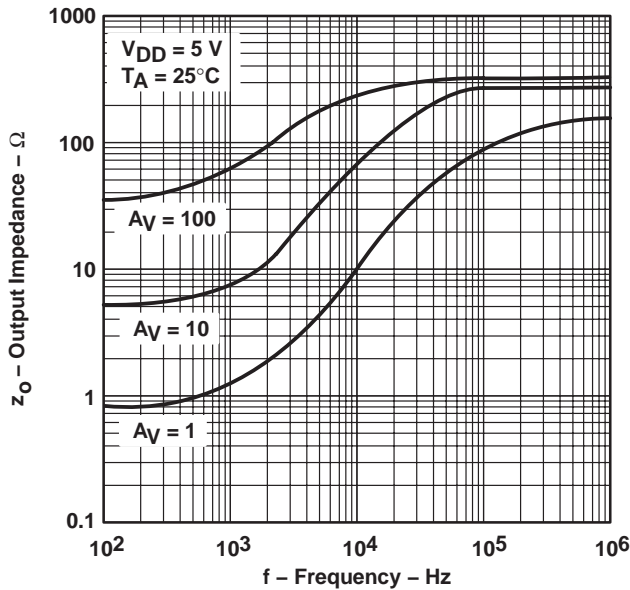


Figure 30

OUTPUT IMPEDANCE  
vs  
FREQUENCY

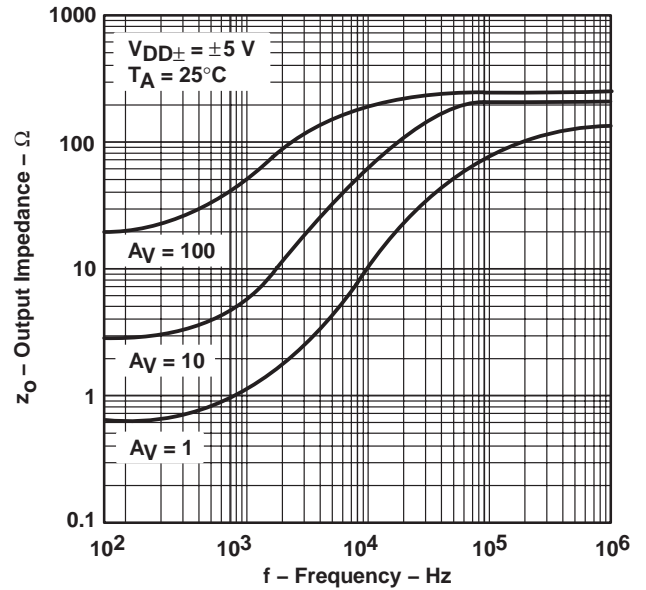
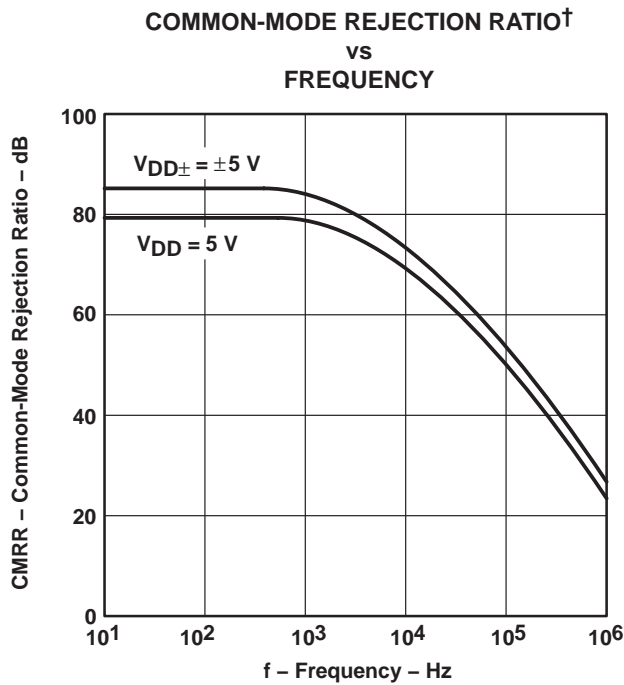


Figure 31

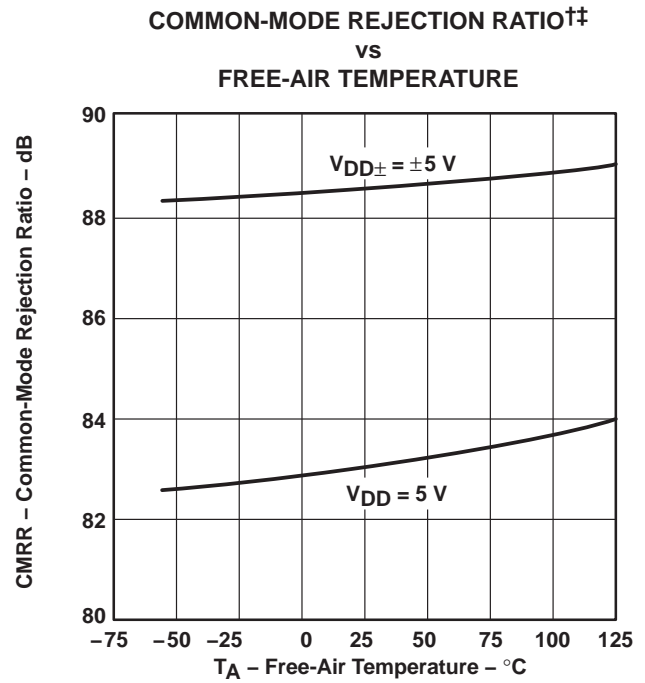
† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

‡ For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to  $2.5\text{ V}$ .

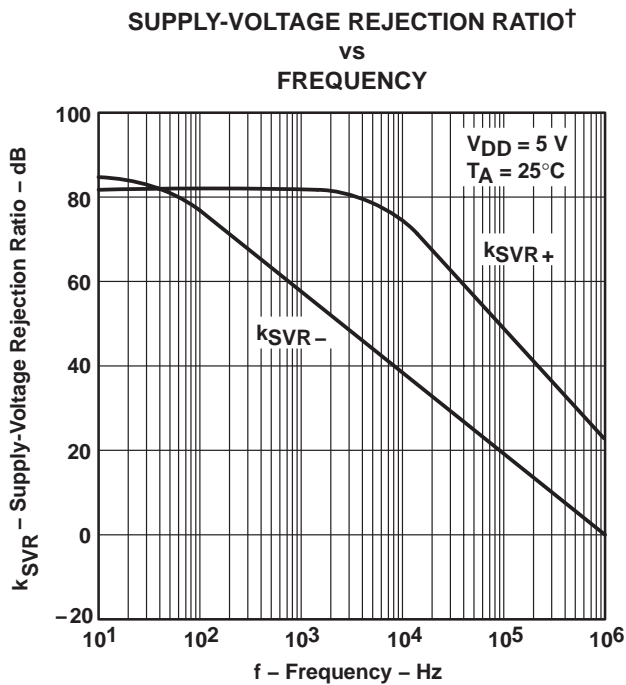
**TYPICAL CHARACTERISTICS**



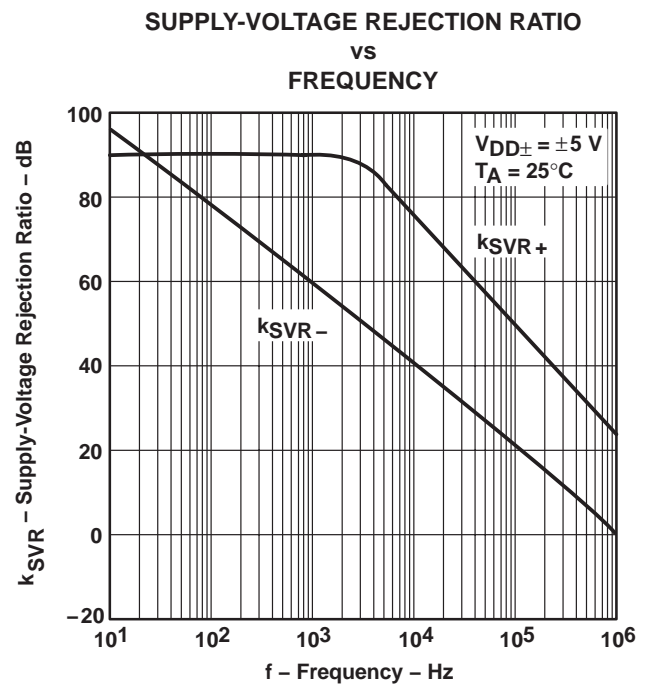
**Figure 32**



**Figure 33**



**Figure 34**

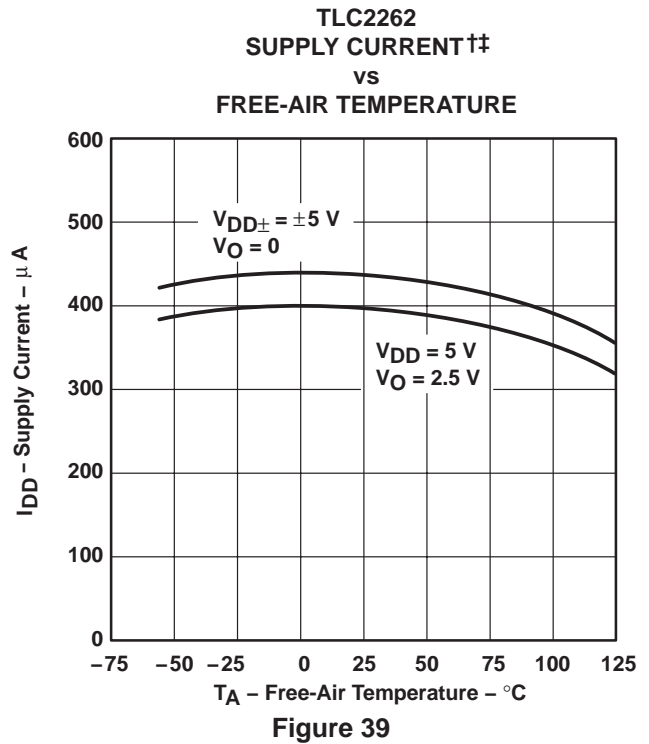
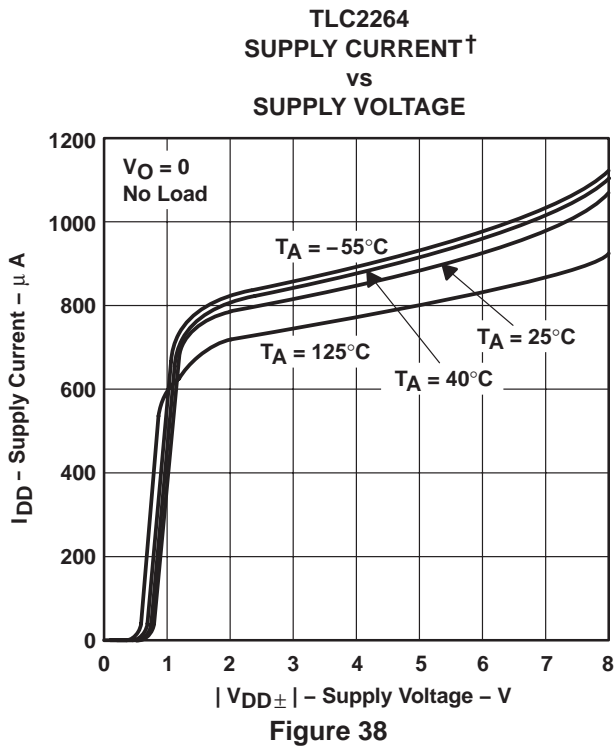
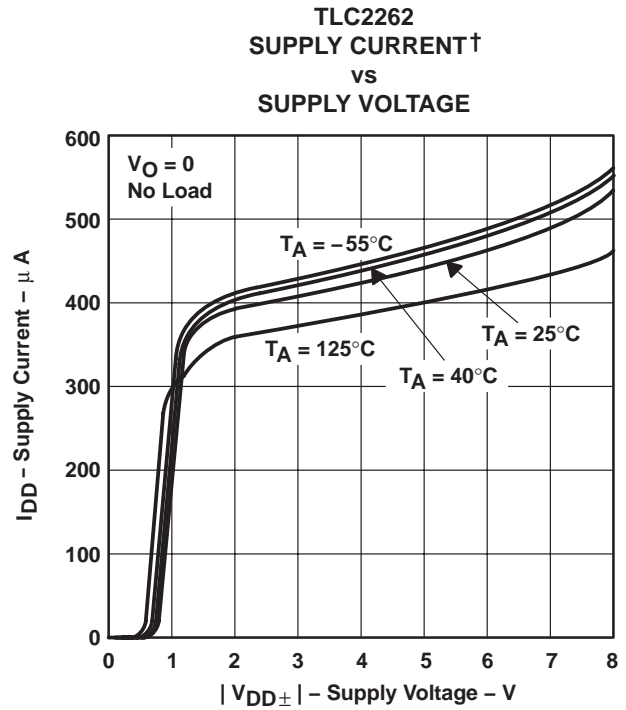
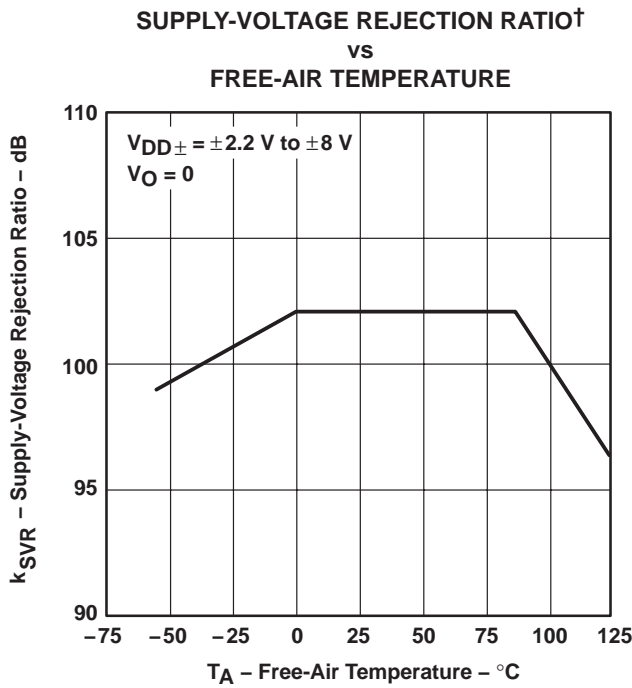


**Figure 35**

† For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to  $2.5\text{ V}$ .

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

TYPICAL CHARACTERISTICS



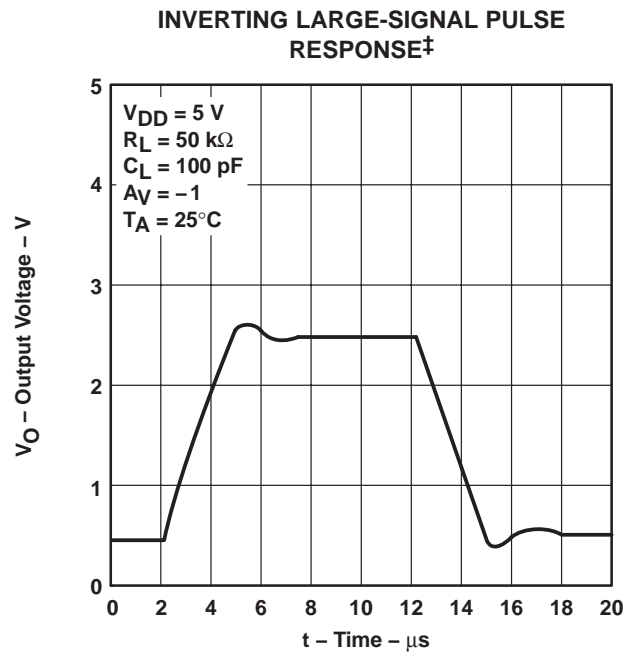
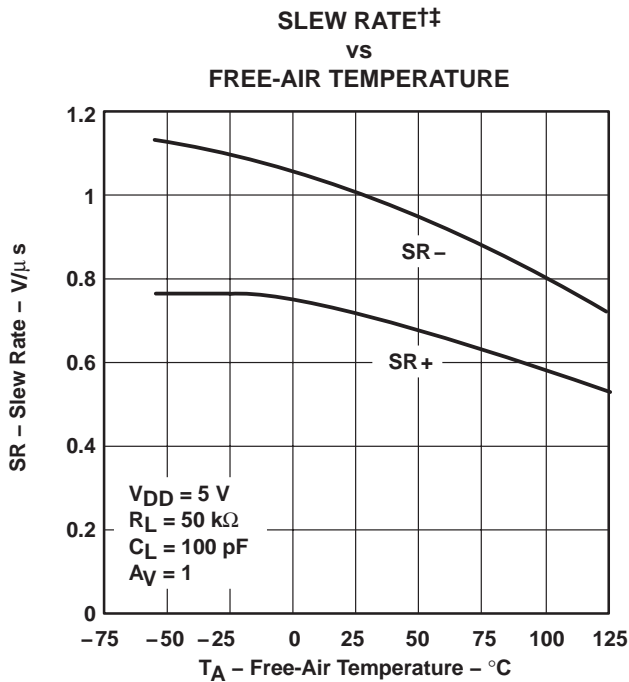
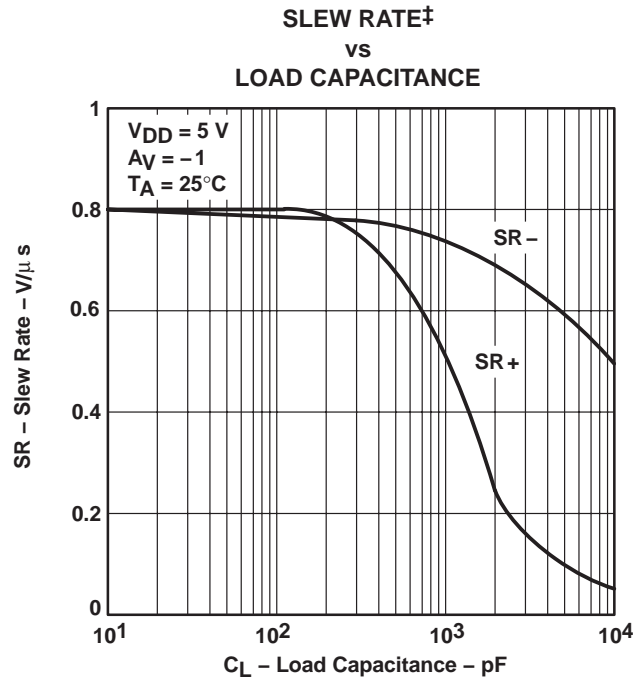
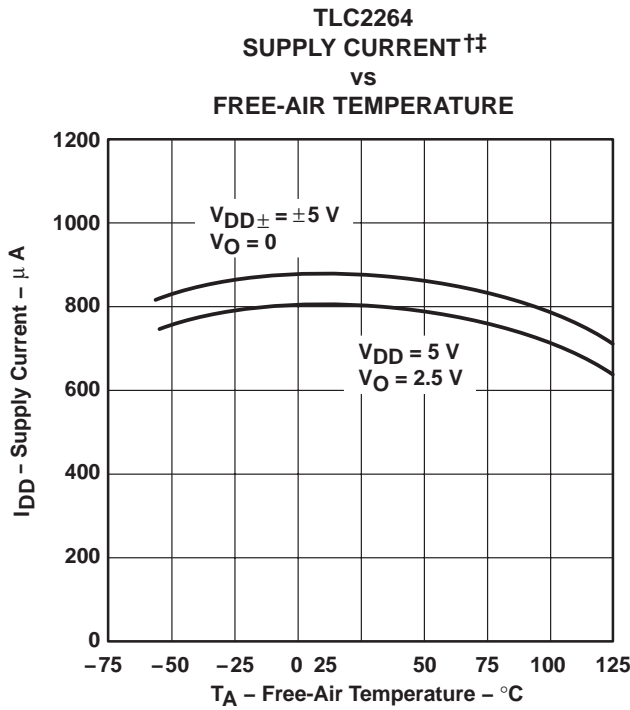
† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

‡ For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.

**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

**TYPICAL CHARACTERISTICS**



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

‡ For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.



TYPICAL CHARACTERISTICS

INVERTING LARGE-SIGNAL PULSE RESPONSE

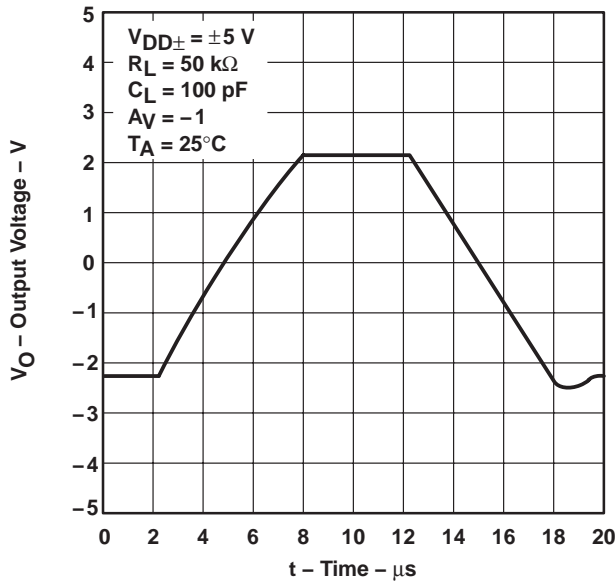


Figure 44

VOLTAGE-FOLLOWER LARGE-SIGNAL PULSE RESPONSE†

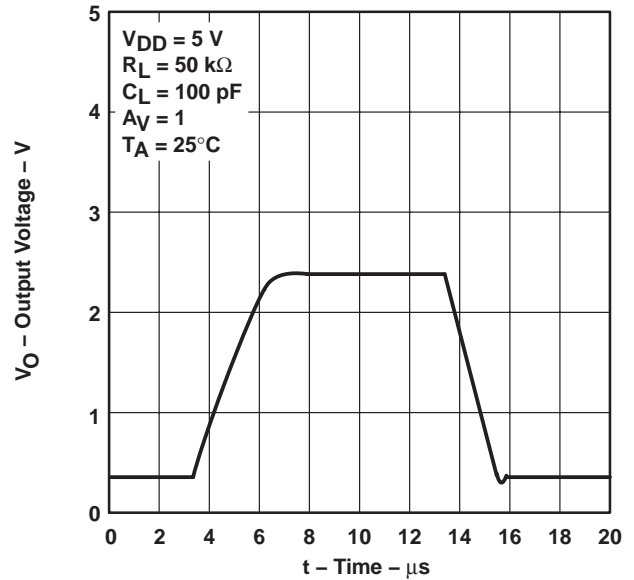


Figure 45

VOLTAGE-FOLLOWER LARGE-SIGNAL PULSE RESPONSE

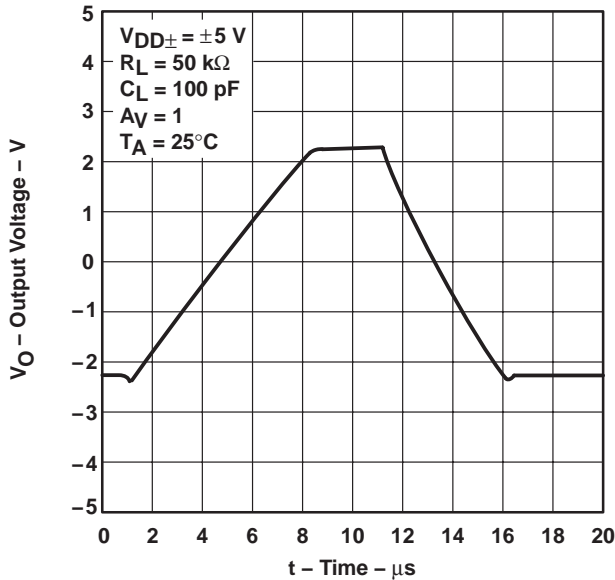


Figure 46

INVERTING SMALL-SIGNAL PULSE RESPONSE†

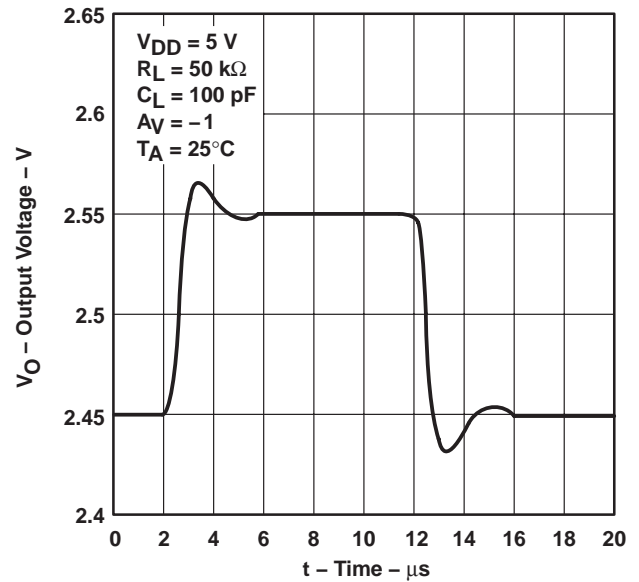
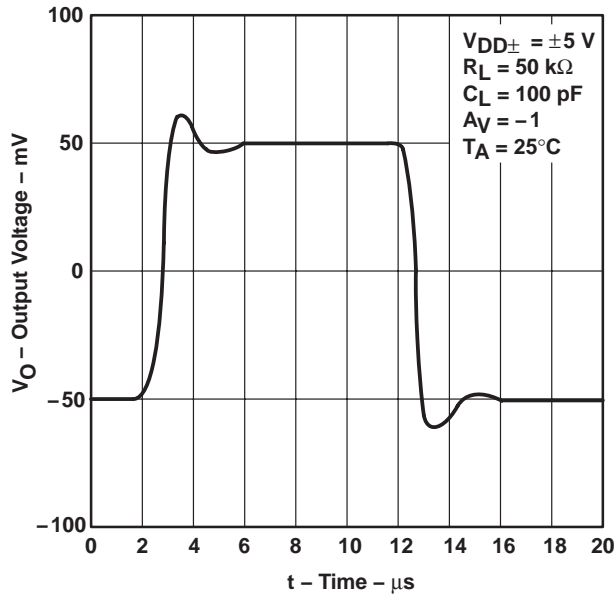


Figure 47

† For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.

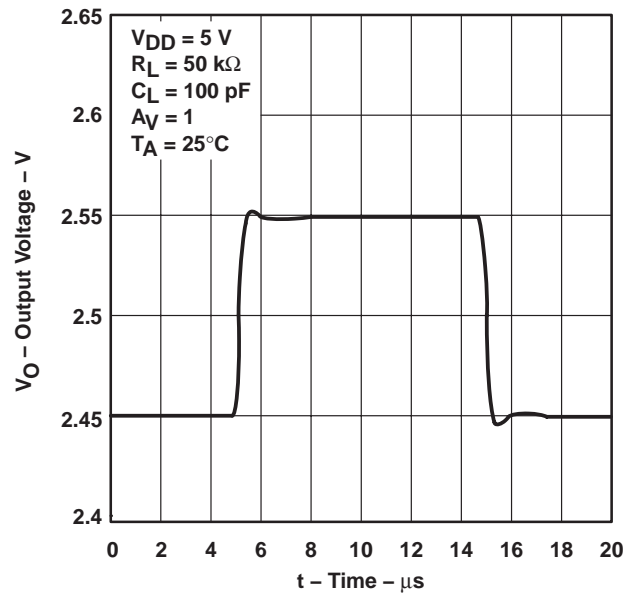
**TYPICAL CHARACTERISTICS**

**INVERTING SMALL-SIGNAL PULSE RESPONSE**



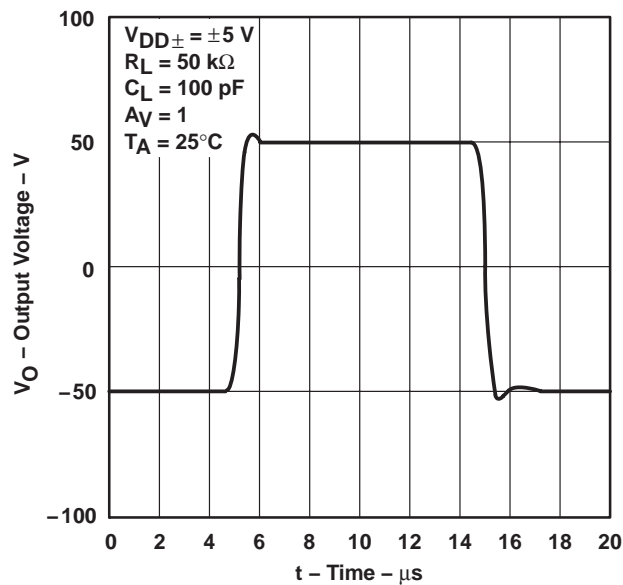
**Figure 48**

**VOLTAGE-FOLLOWER SMALL-SIGNAL PULSE RESPONSE†**



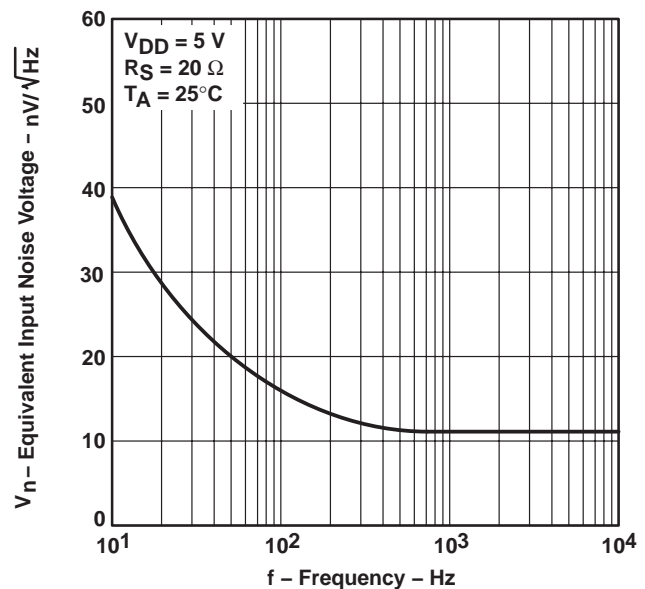
**Figure 49**

**VOLTAGE-FOLLOWER SMALL-SIGNAL PULSE RESPONSE**



**Figure 50**

**EQUIVALENT INPUT NOISE VOLTAGE† vs FREQUENCY**



**Figure 51**

† For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.

TYPICAL CHARACTERISTICS

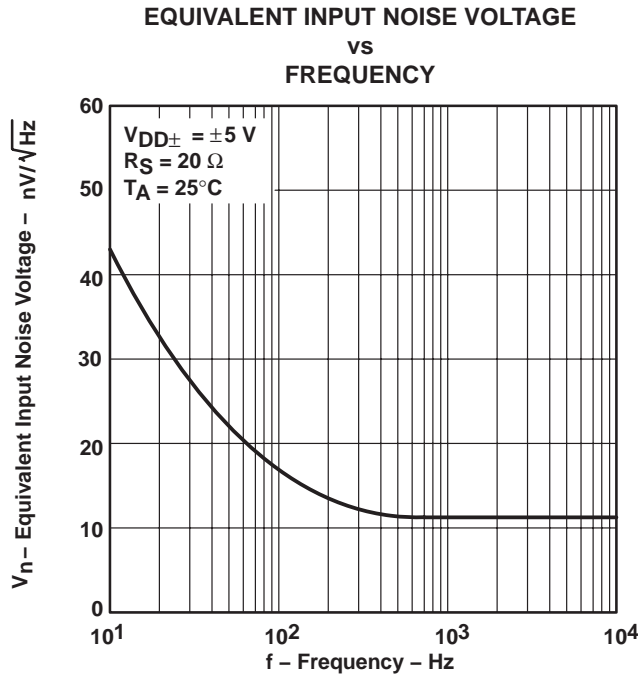


Figure 52

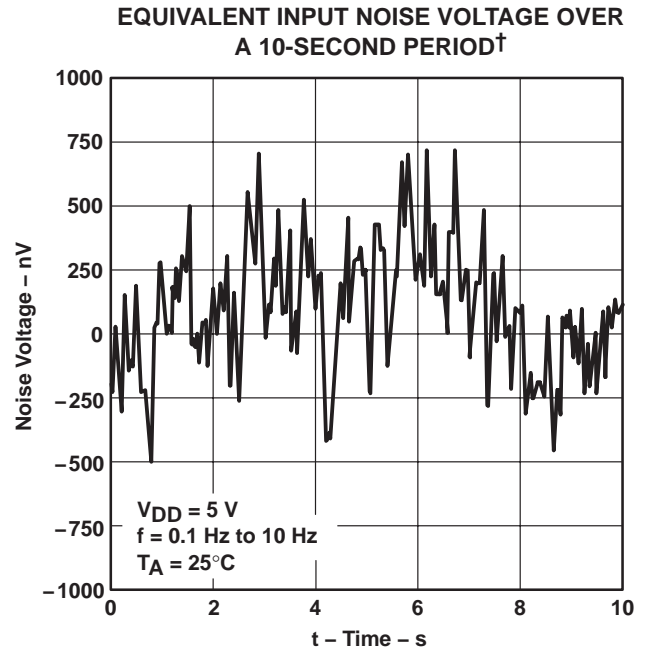


Figure 53

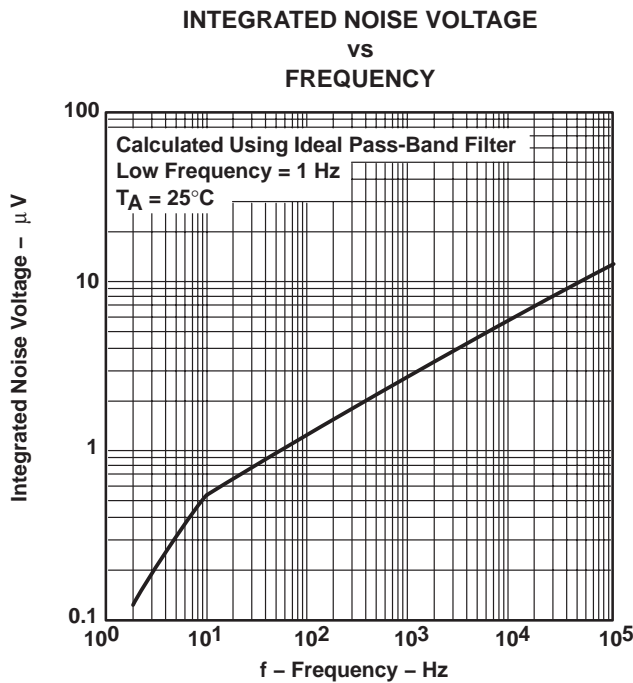


Figure 54

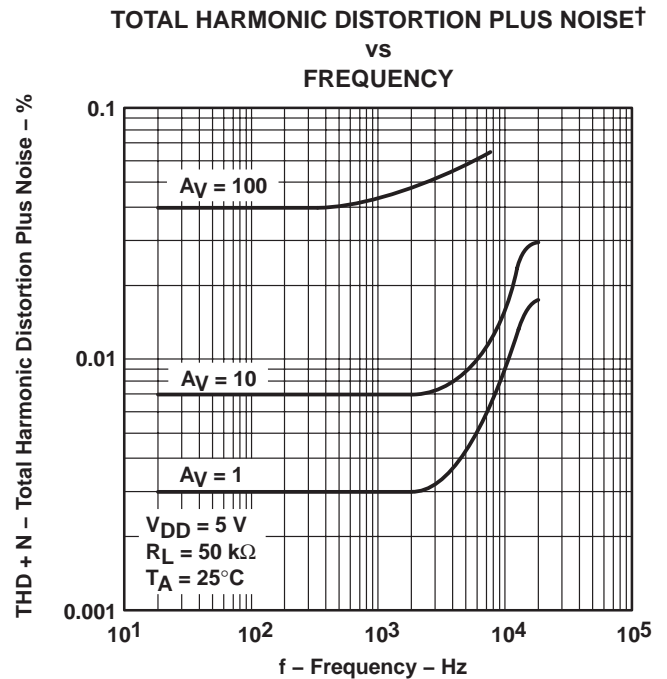


Figure 55

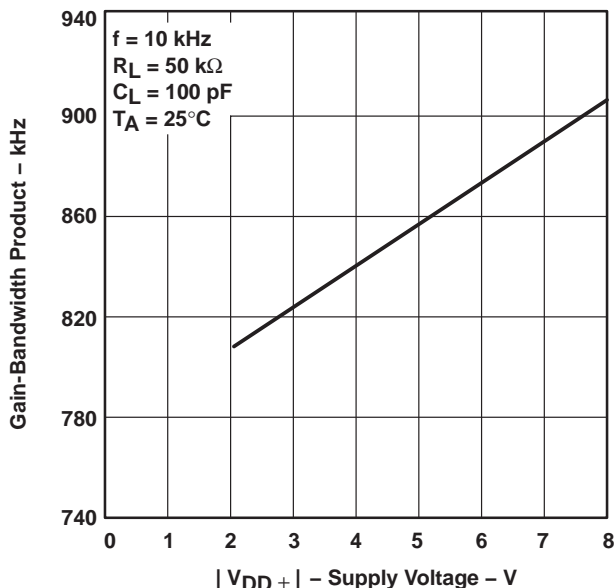
† For curves where  $V_{DD} = 5 V$ , all loads are referenced to 2.5 V.

**TLC226x-Q1, TLC226xA-Q1**  
**Advanced LinCMOS™ RAIL-TO-RAIL**  
**OPERATIONAL AMPLIFIERS**

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

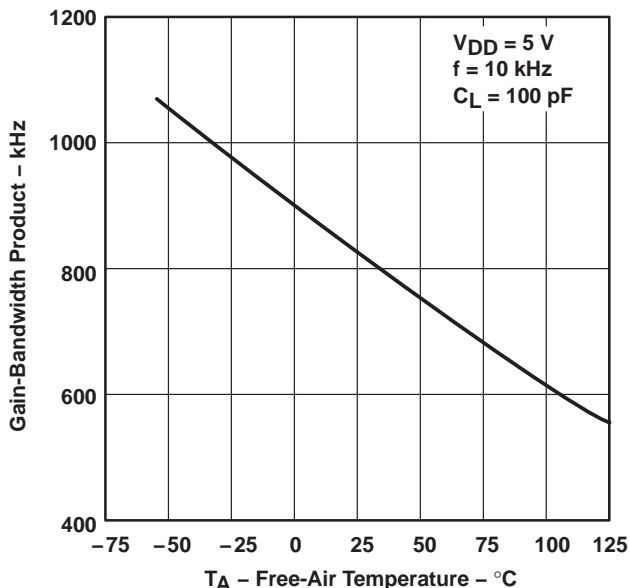
**TYPICAL CHARACTERISTICS**

**GAIN-BANDWIDTH PRODUCT**  
**vs**  
**SUPPLY VOLTAGE**



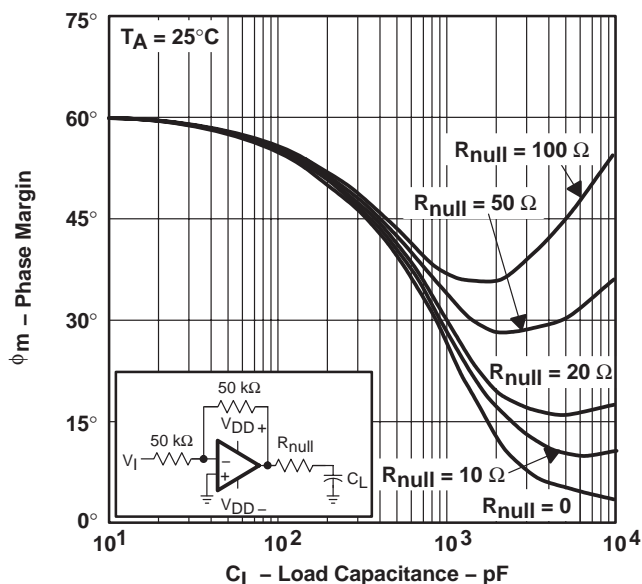
**Figure 56**

**GAIN-BANDWIDTH PRODUCT††**  
**vs**  
**FREE-AIR TEMPERATURE**



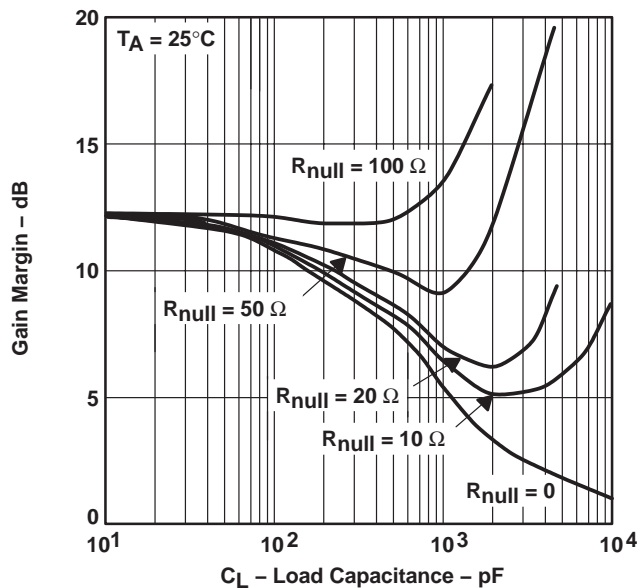
**Figure 57**

**PHASE MARGIN**  
**vs**  
**LOAD CAPACITANCE**



**Figure 58**

**GAIN MARGIN**  
**vs**  
**LOAD CAPACITANCE**



**Figure 59**

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

†† For curves where  $V_{DD} = 5\text{ V}$ , all loads are referenced to 2.5 V.



TYPICAL CHARACTERISTICS

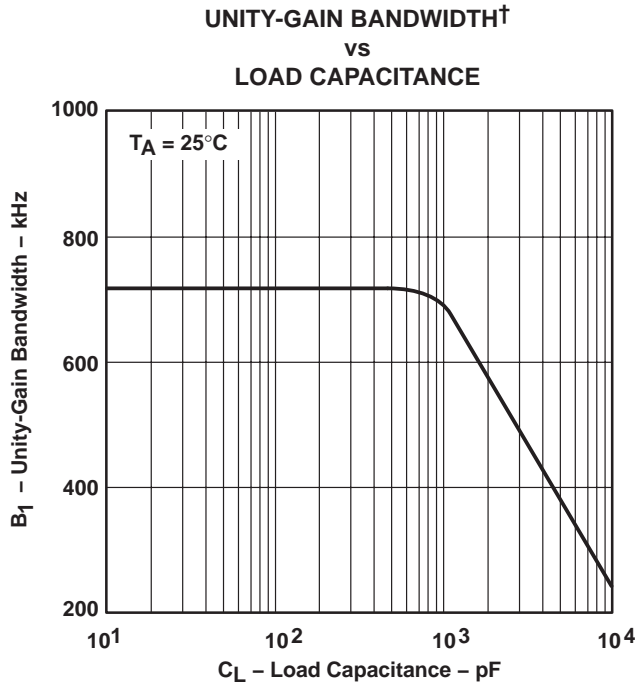


Figure 60

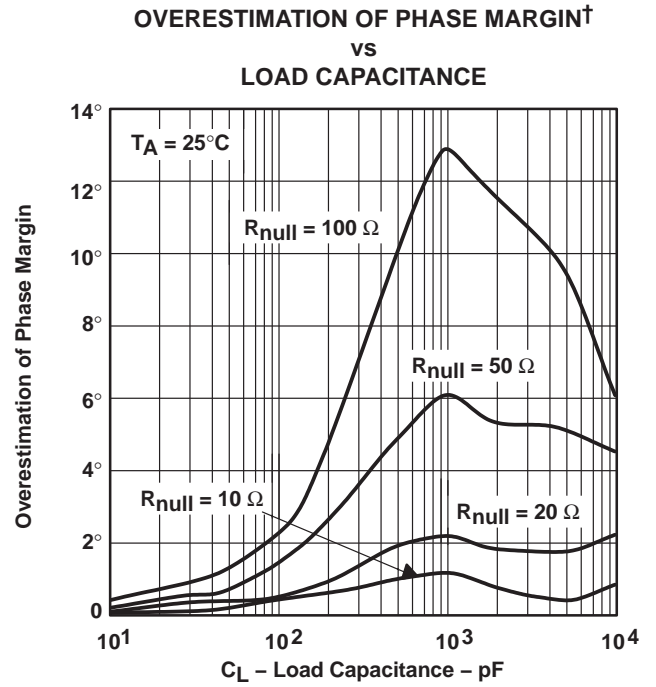


Figure 61

† See application information

**APPLICATION INFORMATION**

**driving large capacitive loads**

The TLC226x is designed to drive larger capacitive loads than most CMOS operational amplifiers. Figure 58 and Figure 59 illustrate its ability to drive loads greater than 400 pF while maintaining good gain and phase margins ( $R_{null} = 0$ ).

A smaller series resistor ( $R_{null}$ ) at the output of the device (see Figure 62) improves the gain and phase margins when driving large capacitive loads. Figure 58 and Figure 59 show the effects of adding series resistances of 10  $\Omega$ , 20  $\Omega$ , 50  $\Omega$ , and 100  $\Omega$ . The addition of this series resistor has two effects: the first is that it adds a zero to the transfer function and the second is that it reduces the frequency of the pole associated with the output load in the transfer function.

The zero introduced to the transfer function is equal to the series resistance times the load capacitance. To calculate the improvement in phase margin, equation 1 can be used.

$$\Delta\theta_{m1} = \tan^{-1} \left( 2 \times \pi \times \text{UGBW} \times R_{null} \times C_L \right) \tag{1}$$

Where :

- $\Delta\theta_{m1}$  = improvement in phase margin
- UGBW = unity-gain bandwidth frequency
- $R_{null}$  = output series resistance
- $C_L$  = load capacitance

The unity-gain bandwidth (UGBW) frequency decreases as the capacitive load increases (see Figure 60). To use equation 1, UGBW must be approximated from Figure 60.

Using equation 1 alone overestimates the improvement in phase margin, as illustrated in Figure 61. The overestimation is caused by the decrease in the frequency of the pole associated with the load, thus providing additional phase shift and reducing the overall improvement in phase margin. The pole associated with the load is reduced by the factor calculated in equation 2.

$$F = \frac{1}{1 + g_m \times R_{null}} \tag{2}$$

Where :

- F = factor reducing frequency of pole
- $g_m$  = small-signal output transconductance (typically  $4.83 \times 10^{-3}$  mhos)
- $R_{null}$  = output series resistance

For the TLC226x, the pole associated with the load is typically 7 MHz with 100-pF load capacitance. This value varies inversely with  $C_L$ : at  $C_L = 10$  pF, use 70 MHz, at  $C_L = 1000$  pF, use 700 kHz, and so on.

Reducing the pole associated with the load introduces phase shift, thereby reducing phase margin. This results in an error in the increase in phase margin expected by considering the zero alone (equation 1). Equation 3 approximates the reduction in phase margin due to the movement of the pole associated with the load. The result of this equation can be subtracted from the result of the equation in equation 1 to better approximate the improvement in phase margin.

**APPLICATION INFORMATION**

**driving large capacitive loads (continued)**

$$\Delta\theta_{m2} = \tan^{-1} \left[ \frac{UGBW}{(F \times P_2)} \right] - \tan^{-1} \left( \frac{UGBW}{P_2} \right) \quad (3)$$

Where :

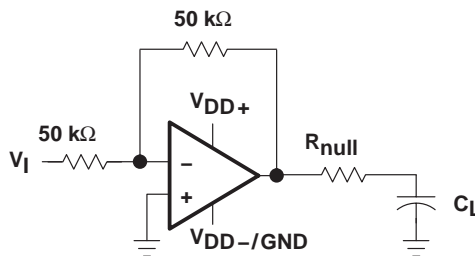
$\Delta\theta_{m2}$  = reduction in phase margin

UGBW = unity-gain bandwidth frequency

F = factor from equation 2

$P_2$  = unadjusted pole (70 MHz @10 pF, 7 MHz @100 pF, etc.)

Using these equations with Figure 60 and Figure 61 enables the designer to choose the appropriate output series resistance to optimize the design of circuits driving large capacitive loads.



**Figure 62. Series-Resistance Circuit**

# TLC226x-Q1, TLC226xA-Q1 Advanced LinCMOS™ RAIL-TO-RAIL OPERATIONAL AMPLIFIERS

SGLS189B – OCTOBER 2003 – REVISED APRIL 2008

## APPLICATION INFORMATION

### macromodel information

Macromodel information provided was derived using Microsim *Parts*™, the model generation software used with Microsim *PSpice*™. The Boyle macromodel (see Note 5) and subcircuit in Figure 63 are generated using the TLC226x typical electrical and operating characteristics at  $T_A = 25^\circ\text{C}$ . Using this information, output simulations of the following key parameters can be generated to a tolerance of 20% (in most cases):

- Maximum positive output voltage swing
- Maximum negative output voltage swing
- Slew rate
- Quiescent power dissipation
- Input bias current
- Open-loop voltage amplification
- Unity-gain frequency
- Common-mode rejection ratio
- Phase margin
- DC output resistance
- AC output resistance
- Short-circuit output current limit

NOTE 4: G. R. Boyle, B. M. Cohn, D. O. Pederson, and J. E. Solomon, "Macromodeling of Integrated Circuit Operational Amplifiers," *IEEE Journal of Solid-State Circuits*, SC-9, 353 (1974).

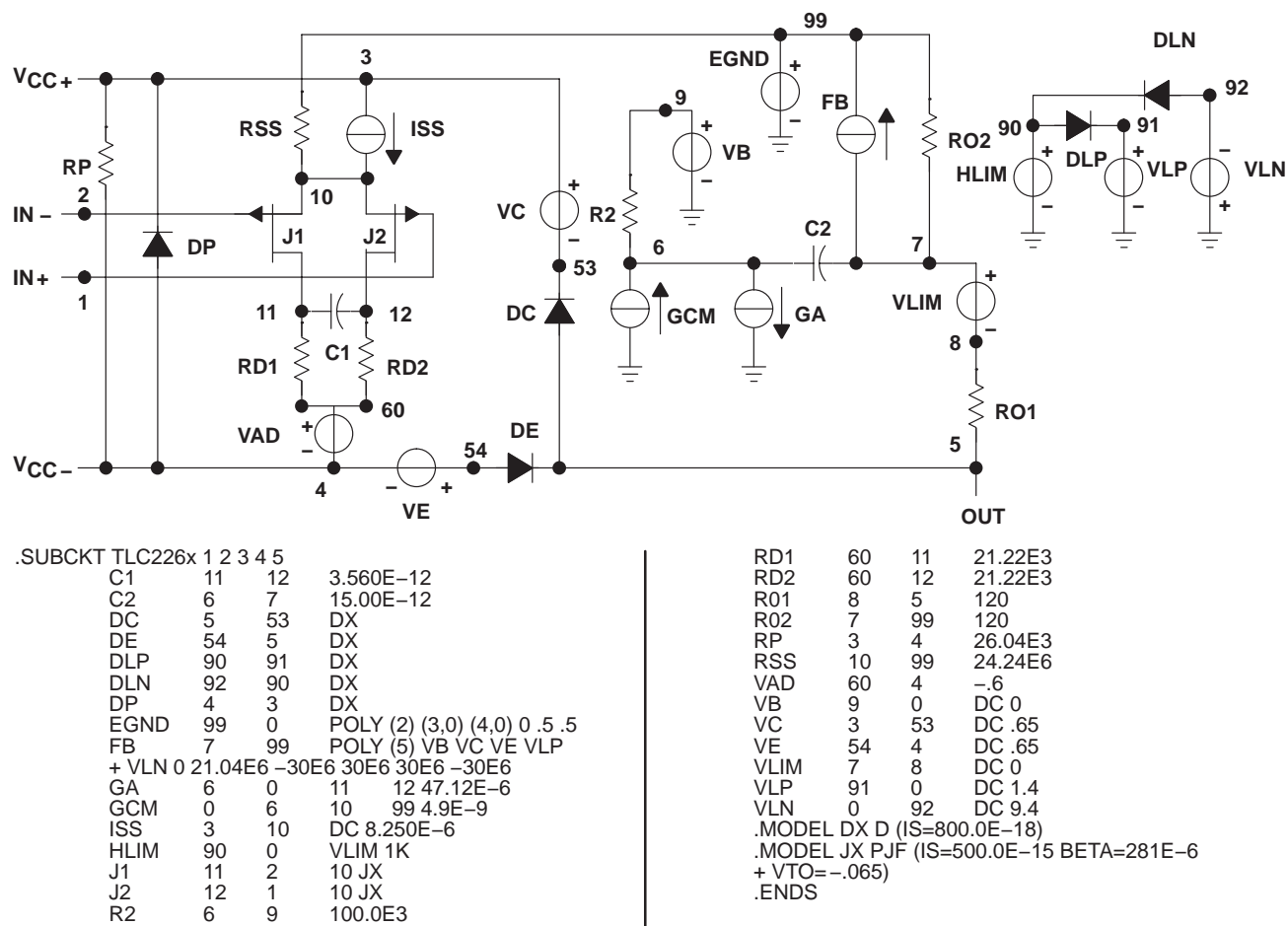


Figure 63. Boyle Macromodel and Subcircuit

*PSpice* and *Parts* are trademarks of MicroSim Corporation.



POST OFFICE BOX 655303 • DALLAS, TEXAS 75265



**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/ Ball Finish	MSL Peak Temp <sup>(3)</sup>	Samples (Requires Login)
TLC2264AQPWRG4Q1	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	<a href="#">Purchase Samples</a>
TLC2264AQPWRQ1	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	<a href="#">Purchase Samples</a>

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBsolete:** TI has discontinued the production of the device.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

**OTHER QUALIFIED VERSIONS OF TLC2264A-Q1 :**

● Catalog: [TLC2264A](#)

● Military: [TLC2264AM](#)

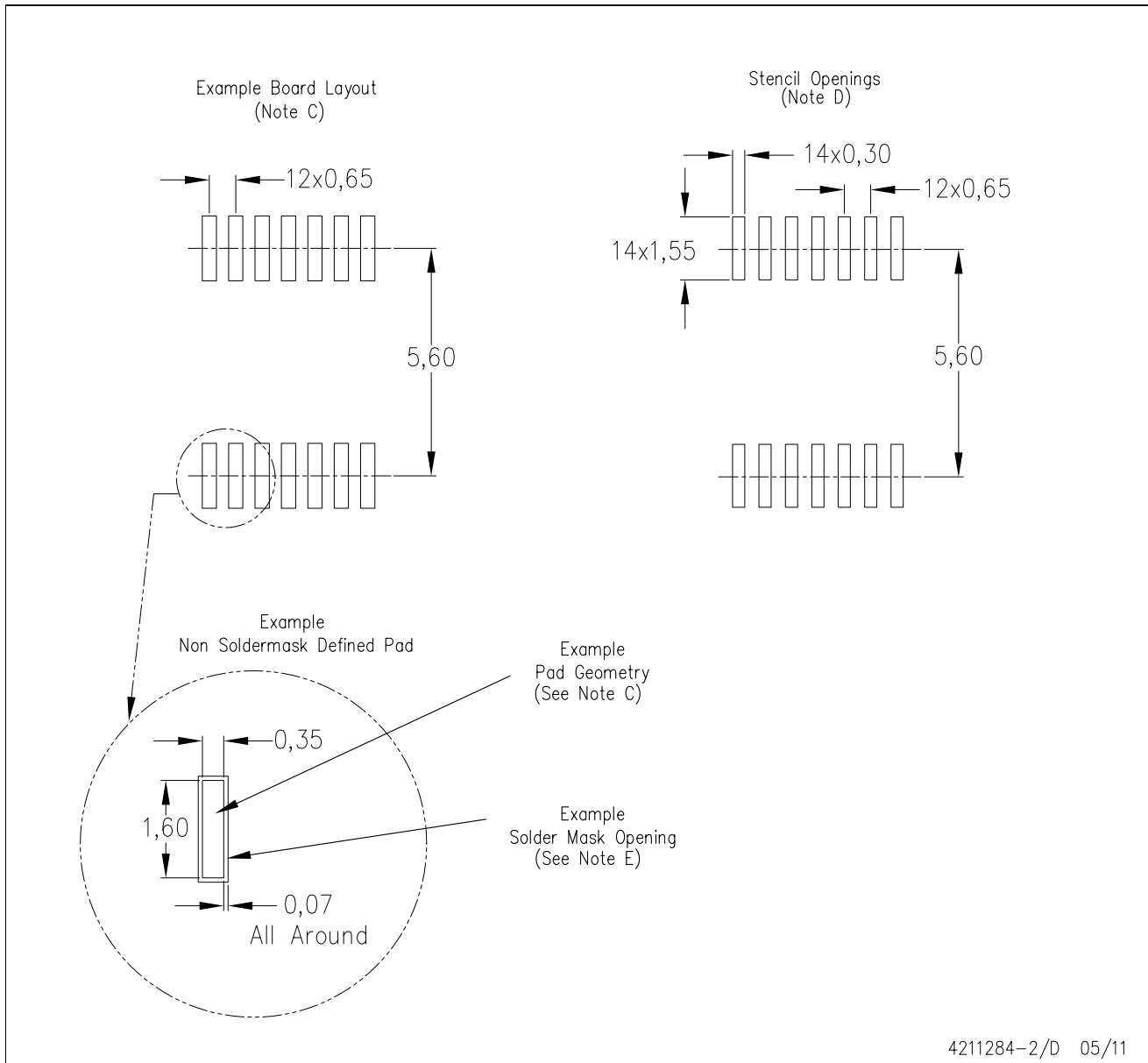
NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product
- Military - QML certified for Military and Defense Applications



PW (R-PDSO-G14)

PLASTIC SMALL OUTLINE



- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Publication IPC-7351 is recommended for alternate designs.
  - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
  - Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
RF/IF and ZigBee® Solutions	<a href="http://www.ti.com/lprf">www.ti.com/lprf</a>

### Applications

Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Transportation and Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>
Wireless	<a href="http://www.ti.com/wireless-apps">www.ti.com/wireless-apps</a>

TI E2E Community Home Page

[e2e.ti.com](http://e2e.ti.com)

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2011, Texas Instruments Incorporated