

TLV225x-Q1, TLV225xA-Q1 Advanced LinCMOS™ RAIL-TO-RAIL VERY LOW-POWER OPERATIONAL AMPLIFIERS

SGLS192B – OCTOBER 2003 – REVISED APRIL 2008

- Qualified for Automotive Applications
- ESD Protection Exceeds 2000 V Per MIL-STD-883, Method 3015; Exceeds 150 V (TLV2252/52A) and 100 V (TLV2254/54A) Using Machine Model (C = 200 pF, R = 0)
- Output Swing Includes Both Supply Rails
- Low Noise . . . 19 nV/√Hz Typ at f = 1 kHz
- Low Input Bias Current . . . 1 pA Typ
- Fully Specified for Both Single-Supply and Split-Supply Operation
- Very Low Power . . . 34 μA Per Channel Typ
- Common-Mode Input Voltage Range Includes Negative Rail
- Low Input Offset Voltage
850 μV Max at T_A = 25°C
- Wide Supply Voltage Range
2.7 V to 16 V
- Macromodel Included

description

The TLV2252 and TLV2254 are dual and quadruple low-voltage operational amplifiers from Texas Instruments. Both devices exhibit rail-to-rail output performance for increased dynamic range in single- or split-supply applications. The TLV225x family consumes only 34 μA of supply current per channel. This micropower operation makes them good choices for battery-powered applications. This family is fully characterized at 3 V and 5 V and is optimized for low-voltage applications. The noise performance has been dramatically improved over previous generations of CMOS amplifiers. The TLV225x has a noise level of 19 nV/√Hz at 1kHz, four times lower than competitive micropower solutions.

The TLV225x, 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 combined with 3-V operation, 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 TLV225xA family is available and has a maximum input offset voltage of 850 μV.

The TLV2252/4 also make great upgrades to the TLV2322/4 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 devices. 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.

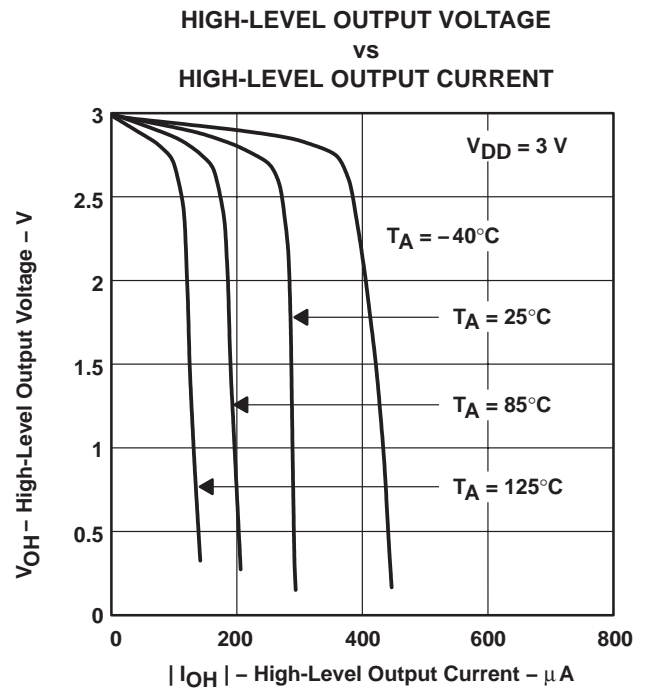


Figure 1



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.

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ORDERING INFORMATION†

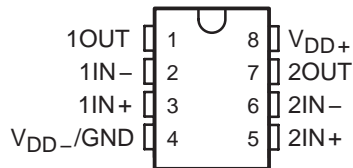
T _A	V _{IO} max AT 25°C	PACKAGE‡		ORDERABLE PART NUMBER	TOP-SIDE MARKING
-40°C to 125°C	850 µV	SOIC (D)	Tape and reel	TLV2252AQDRQ1	2252AQ
		TSSOP (PW)	Tape and reel	TLV2252AQPWRQ1§	
	1500 µV	SOIC (D)	Tape and reel	TLV2252QDRQ1	2252Q1
		TSSOP (PW)	Tape and reel	TLV2252QPWRQ1§	
-40°C to 125°C	850 µV	SOIC (D)	Tape and reel	TLV2254AQDRQ1	TLV2254AQ1
		TSSOP (PW)	Tape and reel	TLV2254AQPWRQ1§	
	1500 µV	SOIC (D)	Tape and reel	TLV2254QDRQ1	TLV2254Q1
		TSSOP (PW)	Tape and reel	TLV2254QPWRQ1§	

† 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>.

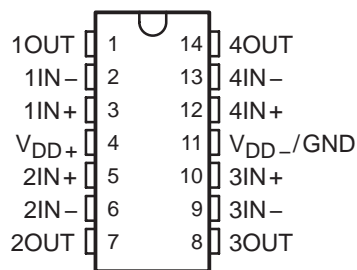
‡ Package drawings, thermal data, and symbolization are available at <http://www.ti.com/packaging>.

§ Product preview

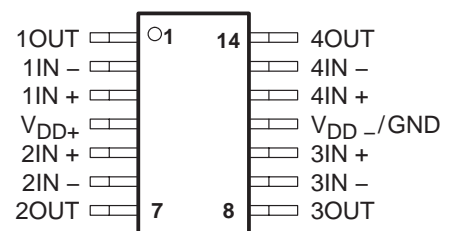
**TLV2252, TLV2252A
D OR PW PACKAGE
(TOP VIEW)**



**TLV2254, TLV2254A
D PACKAGE
(TOP VIEW)**



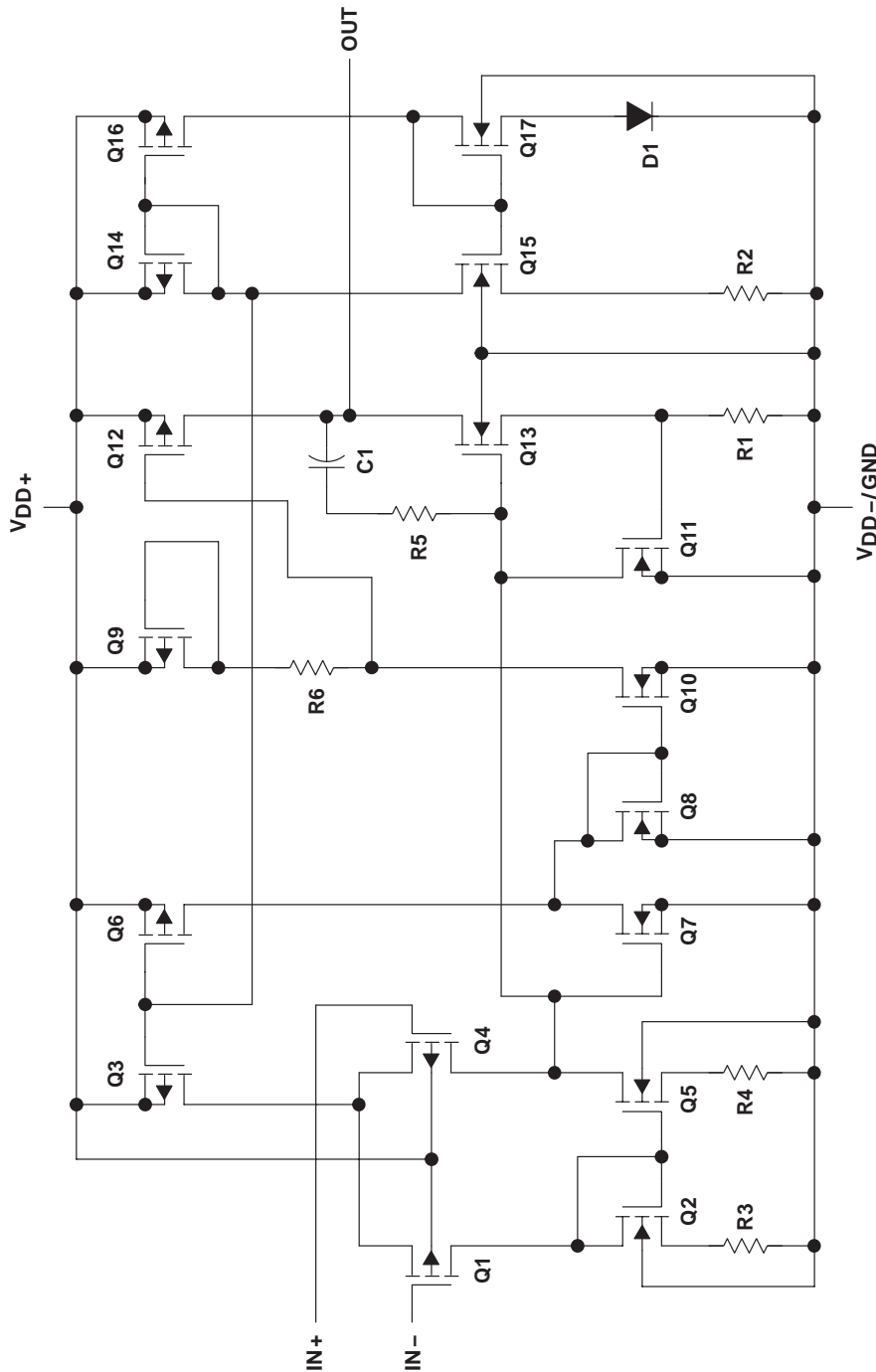
**TLV2254, TLV2254A
PW PACKAGE
(TOP VIEW)**



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equivalent schematic (each amplifier)



ACTUAL DEVICE COMPONENT COUNT†		
COMPONENT	TLV2252	TLV2254
Transistors	38	76
Resistors	30	56
Diodes	9	18
Capacitors	3	6

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

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

Supply voltage, V_{DD} (see Note 1)	16 V
Differential input voltage, V_{ID} (see Note 2)	$\pm V_{DD}$
Input voltage range, V_I (any input, see Note 1)	$V_{DD-} - 0.3 \text{ V to } V_{DD+}$
Input current, I_I (each input)	$\pm 5 \text{ mA}$
Output current, I_O	$\pm 50 \text{ mA}$
Total current into V_{DD+}	$\pm 50 \text{ mA}$
Total current out of V_{DD-}	$\pm 50 \text{ mA}$
Duration of short-circuit current (at or below) 25°C (see Note 3)	unlimited
Continuous total power 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 and PW packages	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 V_{DD-} .
 2. Differential voltages are at the noninverting input with respect to the inverting input. Excessive current flows when 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 $T_A = 25^\circ\text{C}$	$T_A = 85^\circ\text{C}$ POWER RATING	$T_A = 125^\circ\text{C}$ POWER RATING
D-8	725 mW	5.8 mW/°C	377 mW	145 mW
D-14	950 mW	7.6 mW/°C	494 mW	190 mW
PW-8	525 mW	4.2 mW/°C	273 mW	105 mW
PW-14	700 mW	5.6 mW/°C	364 mW	140 mW

recommended operating conditions

	MIN	MAX	UNIT
Supply voltage, V_{DD} (see Note 1)	2.7	16	V
Input voltage range, V_I	V_{DD-}	$V_{DD+} - 1.3$	V
Common-mode input voltage, V_{IC}	V_{DD-}	$V_{DD+} - 1.3$	V
Operating free-air temperature, T_A	-40	125	°C

NOTE 1: All voltage values, except differential voltages, are with respect to V_{DD-} .



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TLV2252-Q1 electrical characteristics at specified free-air temperature, $V_{DD} = 3\text{ V}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_A †	TLV2252-Q1			TLV2252A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO} Input offset voltage		25°C	200	1500		200	850	μV	
		Full range		1750		1000			
α_{VIO} Temperature coefficient of input offset voltage		25°C to 85°C	0.5			0.5			$\mu\text{V}/^\circ\text{C}$
Input offset voltage long-term drift (see Note 4)	$V_{DD\pm} = \pm 1.5\text{ V}$, $V_O = 0$, $V_{IC} = 0$, $R_S = 50\ \Omega$	25°C	0.003			0.003			$\mu\text{V}/\text{mo}$
I_{IO} Input offset current		25°C	0.5	60		0.5	60	pA	
		125°C	1000			1000			
I_{IB} Input bias current		25°C	1	60		1	60	pA	
		125°C	1000			1000			
V_{ICR} Common-mode input voltage range		$R_S = 50\ \Omega$, $ V_{IO} \leq 5\text{ mV}$	25°C	0 to 2	-0.3 to 2.2		0 to 2	-0.3 to 2.2	V
	Full range		0 to 1.7			0 to 1.7			
V_{OH} High-level output voltage	$I_{OH} = -20\ \mu\text{A}$	25°C	2.98			2.98			V
	$I_{OH} = -75\ \mu\text{A}$	25°C	2.9			2.9			
	$I_{OH} = -150\ \mu\text{A}$	Full range	2.8			2.8			
V_{OL} Low-level output voltage	$V_{IC} = 1.5\text{ V}$, $I_{OL} = 50\ \mu\text{A}$	25°C	10			10			mV
		25°C	100	150		100	150		
	$V_{IC} = 1.5\text{ V}$, $I_{OL} = 500\ \mu\text{A}$	Full range	165			165			
		$V_{IC} = 1.5\text{ V}$, $I_{OL} = 1\text{ mA}$	25°C	200	300		200	300	
Full range	300			300					
A_{VD} Large-signal differential voltage amplification	$V_{IC} = 1.5\text{ V}$, $V_O = 1\text{ V to }2\text{ V}$	$R_L = 100\text{ k}\Omega$ ‡	25°C	100	250		100	250	V/mV
			Full range	10			10		
		$R_L = 1\text{ M}\Omega$ ‡	25°C	800			800		
$r_{i(d)}$ Differential input resistance		25°C	10^{12}			10^{12}			Ω
$r_{i(c)}$ Common-mode input resistance		25°C	10^{12}			10^{12}			Ω
$C_{i(c)}$ Common-mode input capacitance	$f = 10\text{ kHz}$	25°C	8			8			pF
z_o Closed-loop output impedance	$f = 25\text{ kHz}$, $A_V = 10$	25°C	220			220			Ω
CMRR Common-mode rejection ratio	$V_{IC} = 0\text{ to }1.7\text{ V}$, $V_O = 1.5\text{ V}$, $R_S = 50\ \Omega$	25°C	65	75		65	77	dB	
		Full range	60			60			
k_{SVR} Supply voltage rejection ratio ($\Delta V_{DD} / \Delta V_{IO}$)	$V_{DD} = 2.7\text{ V to }8\text{ V}$, $V_{IC} = V_{DD}/2$, No load	25°C	80	95		80	100	dB	
		Full range	80			80			
I_{DD} Supply current	$V_O = 1.5\text{ V}$, No load	25°C	68	125		68	125	μA	
		Full range	150			150			

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

‡ Referenced to 1.5 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.



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TLV2252-Q1 operating characteristics at specified free-air temperature, $V_{DD} = 3\text{ V}$

PARAMETER	TEST CONDITIONS	T_A †	TLV2252-Q1			TLV2252A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
SR	Slew rate at unity gain $V_O = 0.8\text{ V to }1.4\text{ V}$, $R_L = 100\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	0.07	0.1		0.07	0.1	V/ μ s	
		Full range	0.05			0.05			
V_n	Equivalent input noise voltage $f = 10\text{ Hz}$ $f = 1\text{ kHz}$	25°C	35			35			nV/ $\sqrt{\text{Hz}}$
		25°C	19			19			
$V_{N(PP)}$	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	0.6			0.6			μ V
		25°C	1.1			1.1			
I_n	Equivalent input noise current	25°C	0.6			0.6			fA/ $\sqrt{\text{Hz}}$
	Gain-bandwidth product $f = 1\text{ kHz}$, $R_L = 50\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	0.187			0.187			MHz
BOM	Maximum output-swing bandwidth $V_{O(PP)} = 1\text{ V}$, $R_L = 50\text{ k}\Omega$ ‡, $A_V = 1$, $C_L = 100\text{ pF}$ ‡	25°C	60			60			kHz
ϕ_m	Phase margin at unity gain $R_L = 50\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	63°			63°			
		25°C	15			15			dB

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

‡ Referenced to 1.5 V



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TLV2252-Q1 electrical characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_A †	TLV2252-Q1			TLV2252A-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	200	1500		200	850	μV	
		Full range			1750		1000		
α_{VIO} Temperature coefficient of input offset voltage		25°C to 85°C	0.5			0.5		$\mu\text{V}/^\circ\text{C}$	
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	60		0.5	60	pA	
		125°C			1000		1000		
I_{IB} Input bias current	25°C	1	60		1	60	pA		
	125°C			1000		1000			
V_{ICR} Common-mode input voltage range	$ V_{IO} \leq 5\text{ mV}$, $R_S = 50\ \Omega$	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	$I_{OH} = -20\ \mu\text{A}$ $I_{OH} = -75\ \mu\text{A}$ $I_{OH} = -150\ \mu\text{A}$	25°C	4.98			4.98		V	
		25°C	4.9	4.94		4.9	4.94		
		Full range	4.8			4.8			
		25°C	4.8	4.88		4.8	4.88		
V_{OL} Low-level output voltage	$V_{IC} = 2.5\text{ V}$, $I_{OL} = 50\ \mu\text{A}$ $I_{OL} = 500\ \mu\text{A}$ $I_{OL} = 1\text{ mA}$	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	0.2	0.3		0.2	0.3		
		Full range			0.3		0.3		
A_{VD} Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$, $V_O = 1\text{ V to }4\text{ V}$	$R_L = 100\text{ k}\Omega$ †	25°C	100	350		100	350	V/mV
			Full range	10			10		
		$R_L = 1\text{ M}\Omega$ ‡	25°C		1700			1700	
$r_{i(d)}$ Differential input resistance		25°C		10^{12}			10^{12}	Ω	
$r_{i(c)}$ Common-mode input resistance		25°C		10^{12}			10^{12}	Ω	
$c_{i(c)}$ Common-mode input capacitance	$f = 10\text{ kHz}$	25°C		8			8	pF	
z_o Closed-loop output impedance	$f = 25\text{ kHz}$, $A_V = 10$	25°C		200			200	Ω	
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 ($\Delta V_{DD}/\Delta V_{IO}$)	$V_{DD} = 4.4\text{ V to }8\text{ V}$, $V_{IC} = V_{DD}/2$, No load	25°C	80	95		80	95	dB	
		Full range	80			80			

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

‡ 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.



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TLV2252-Q1 electrical characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$ (unless otherwise noted) (continued)

PARAMETER	TEST CONDITIONS	T_A †	TLV2252-Q1			TLV2252A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
I_{DD} Supply current	$V_O = 2.5\text{ V}$, No load	25°C	70	125		70	125	μA	
		Full range		150		150			

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

TLV2252-Q1 operating characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$

PARAMETER	TEST CONDITIONS	T_A †	TLV2252-Q1			TLV2252A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
SR Slew rate at unity gain	$V_O = 1.25\text{ V}$ to 2.75 V , $R_L = 100\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	0.07	0.12		0.07	0.12	$\text{V}/\mu\text{s}$	
		Full range	0.05			0.05			
V_n Equivalent input noise voltage	$f = 10\text{ Hz}$	25°C		36			36	$\text{nV}/\sqrt{\text{Hz}}$	
	$f = 1\text{ kHz}$	25°C		19			19		
$V_{N(PP)}$ Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz}$ to 1 Hz	25°C		0.7			0.7	μV	
	$f = 0.1\text{ Hz}$ to 10 Hz	25°C		1.1			1.1		
I_n Equivalent input noise current		25°C		0.6			0.6	$\text{fA}/\sqrt{\text{Hz}}$	
THD + N Total harmonic distortion plus noise	$V_O = 0.5\text{ V}$ to 2.5 V , $f = 20\text{ kHz}$, $R_L = 50\text{ k}\Omega$ ‡	25°C		$A_V = 1$		0.2%		0.2%	
				$A_V = 10$		1%		1%	
Gain-bandwidth product	$f = 50\text{ kHz}$, $C_L = 100\text{ pF}$ ‡	25°C		0.2			0.2	MHz	
BOM Maximum output-swing bandwidth	$V_{O(PP)} = 2\text{ V}$, $R_L = 50\text{ k}\Omega$ ‡	25°C		30			30	kHz	
ϕ_m Phase margin at unity gain	$R_L = 50\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C		63°			63°		
		25°C		15			15	dB	
Gain margin		25°C		15			15	dB	

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

‡ Referenced to 2.5 V



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TLV2254-Q1 electrical characteristics at specified free-air temperature, $V_{DD} = 3\text{ V}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_A †	TLV2254-Q1			TLV2254A-Q1			UNIT	
			MIN	TYP	MAX	MIN	TYP	MAX		
V_{IO} Input offset voltage		25°C	200	1500		200	850	μV		
		Full range			1750		1000			
α_{VIO} Temperature coefficient of input offset voltage		25°C to 125°C	0.5			0.5			$\mu\text{V}/^\circ\text{C}$	
Input offset voltage long-term drift (see Note 4)	$V_{DD} \pm \pm 1.5\text{ V}$, $V_O = 0$,	25°C	0.003			0.003			$\mu\text{V}/\text{mo}$	
I_{IO} Input offset current		25°C	0.5	60		0.5	60	pA		
		125°C			1000		1000			
I_{IB} Input bias current		25°C	1	60		1	60	pA		
		125°C			1000		1000			
V_{ICR} Common-mode input voltage range	$R_S = 50\ \Omega$, $ V_{IO} \leq 5\text{ mV}$	25°C	0 to 2	-0.3 to 2.2		0 to 2	-0.3 to 2.2	V		
		Full range	0 to 1.7			0 to 1.7				
V_{OH} High-level output voltage	$I_{OH} = -20\ \mu\text{A}$	25°C	2.98			2.98			V	
	$I_{OH} = -75\ \mu\text{A}$	25°C	2.9			2.9				
	Full range		2.8			2.8				
V_{OL} Low-level output voltage	$V_{IC} = 1.5\text{ V}$, $I_{OL} = 50\ \mu\text{A}$	25°C	10			10			mV	
	$V_{IC} = 1.5\text{ V}$, $I_{OL} = 500\ \mu\text{A}$	25°C	100	150		100	150			
	Full range		165			165				
	$V_{IC} = 1.5\text{ V}$, $I_{OL} = 1\text{ mA}$	25°C	200	300		200	300			
A_{VD} Large-signal differential voltage amplification	$V_{IC} = 1.5\text{ V}$, $V_O = 1\text{ V to }2\text{ V}$	$R_L = 100\text{ k}\Omega$ ‡	25°C	100	225		100	225	V/mV	
		Full range		10			10			
		$R_L = 1\text{ M}\Omega$ ‡	25°C	800			800			
$r_{i(d)}$ Differential input resistance		25°C	10^{12}			10^{12}			Ω	
$r_{i(c)}$ Common-mode input resistance		25°C	10^{12}			10^{12}			Ω	
$c_{i(c)}$ Common-mode input capacitance	$f = 10\text{ kHz}$	25°C	8			8			pF	
z_o Closed-loop output impedance	$f = 25\text{ kHz}$, $A_V = 10$	25°C	220			220			Ω	
CMRR Common-mode rejection ratio	$V_{IC} = 0\text{ to }1.7\text{ V}$, $V_O = 1.5\text{ V}$, $R_S = 50\ \Omega$	25°C	65	75		65	77	dB		
		Full range	60			60				
k_{SVR} Supply voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)	$V_{DD} = 2.7\text{ V to }8\text{ V}$, $V_{IC} = V_{DD}/2$, No load	25°C	80	95		80	100	dB		
		Full range	80			80				

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

‡ Referenced to 1.5 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.



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TLV2254-Q1 electrical characteristics at specified free-air temperature, $V_{DD} = 3\text{ V}$ (unless otherwise noted) (continued)

PARAMETER	TEST CONDITIONS	T_A †	TLV2254-Q1			TLV2254A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
I_{DD}	Supply current (four amplifiers)	$V_O = 1.5\text{ V}$, No load	25°C	135	250	135	250	μA	
			Full range	300			300		

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

TLV2254-Q1 operating characteristics at specified free-air temperature, $V_{DD} = 3\text{ V}$

PARAMETER	TEST CONDITIONS	T_A †	TLV2254-Q1			TLV2254A-Q1			UNIT	
			MIN	TYP	MAX	MIN	TYP	MAX		
SR	Slew rate at unity gain	$V_O = 0.5\text{ V}$ to 1.7 V , $R_L = 100\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	0.07	0.1	0.07	0.1	$\text{V}/\mu\text{s}$		
			Full range	0.05			0.05			
V_n	Equivalent input noise voltage	$f = 10\text{ Hz}$	25°C	35			35			$\text{nV}/\sqrt{\text{Hz}}$
			$f = 1\text{ kHz}$	19			19			
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz}$ to 1 Hz	25°C	0.6			0.6			μV
			$f = 0.1\text{ Hz}$ to 10 Hz	1.1			1.1			
I_n	Equivalent input noise current		25°C	0.6			0.6			$\text{fA}/\sqrt{\text{Hz}}$
	Gain-bandwidth product	$f = 1\text{ kHz}$, $R_L = 50\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	0.187			0.187			MHz
BOM	Maximum output-swing bandwidth	$V_{O(PP)} = 1\text{ V}$, $A_V = 1$, $R_L = 50\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	60			60			kHz
ϕ_m	Phase margin at unity gain	$R_L = 50\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	63°			63°			
	Gain margin		25°C	15			15			dB

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

‡ Referenced to 1.5 V



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TLV2254-Q1 electrical characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_A †	TLV2254-Q1			TLV2254A-Q1			UNIT	
			MIN	TYP	MAX	MIN	TYP	MAX		
V_{IO} Input offset voltage		25°C	200		1500	200		850	μV	
		Full range	1750			1000				
α_{VIO} Temperature coefficient of input offset voltage		25°C to 125°C	0.5			0.5			$\mu\text{V}/^\circ\text{C}$	
Input offset voltage long-term drift (see Note 4)	$V_{DD\pm} = \pm 2.5\text{ V}$, $V_{IC} = 0$, $V_O = 0$, $R_S = 50\ \Omega$	25°C	0.003			0.003			$\mu\text{V}/\text{mo}$	
I_{IO} Input offset current		25°C	0.5		60	0.5		60	pA	
		125°C	1000			1000				
I_{IB} Input bias current		25°C	1		60	1		60	pA	
	125°C	1000			1000					
V_{ICR} Common-mode input voltage range	$ V_{IO} \leq 5\text{ mV}$, $R_S = 50\ \Omega$	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	$I_{OH} = -20\ \mu\text{A}$ $I_{OH} = -75\ \mu\text{A}$ $I_{OH} = -150\ \mu\text{A}$	25°C	4.98			4.98			V	
		25°C	4.9	4.94		4.9	4.94			
		Full range	4.8			4.8				
		25°C	4.8	4.88		4.8	4.88			
V_{OL} Low-level output voltage	$V_{IC} = 2.5\text{ V}$, $I_{OL} = 50\ \mu\text{A}$ $V_{IC} = 2.5\text{ V}$, $I_{OL} = 500\ \mu\text{A}$ $V_{IC} = 2.5\text{ V}$, $I_{OL} = 1\text{ mA}$	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	0.2	0.3		0.2	0.3			
		Full range	0.3			0.3				
A_{VD} Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$, $V_O = 1\text{ V to }4\text{ V}$	$R_L = 100\text{ k}\Omega$ ‡	25°C	100	350		100	350		V/mV
			Full range	10			10			
		$R_L = 1\text{ M}\Omega$ ‡	25°C	1700			1700			
$r_{i(d)}$ Differential input resistance		25°C	10^{12}			10^{12}			Ω	
$r_{i(c)}$ Common-mode input resistance		25°C	10^{12}			10^{12}			Ω	
$c_{i(c)}$ Common-mode input capacitance	$f = 10\text{ kHz}$	25°C	8			8			pF	
z_o Closed-loop output impedance	$f = 25\text{ kHz}$, $A_V = 10$	25°C	200			200			Ω	
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 ($\Delta V_{DD}/\Delta V_{IO}$)	$V_{DD} = 4.4\text{ V to }8\text{ V}$, $V_{IC} = V_{DD}/2$, No load	25°C	80	95		80	95		dB	
		Full range	80			80				

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

‡ 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.



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TLV2254-Q1 electrical characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$ (unless otherwise noted) (continued)

PARAMETER	TEST CONDITIONS	T_A †	TLV2254-Q1			TLV2254A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
I_{DD} Supply current (four amplifiers)	$V_O = 2.5\text{ V}$, No load	25°C	140	250		140	250	μA	
		Full range		300			300		

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

TLV2254-Q1 operating characteristics at specified free-air temperature, $V_{DD} = 5\text{ V}$

PARAMETER	TEST CONDITIONS	T_A †	TLV2254-Q1			TLV2254A-Q1			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
SR Slew rate at unity gain	$V_O = 0.5\text{ V}$ to 3.5 V , $R_L = 100\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C	0.07	0.12		0.07	0.12	$\text{V}/\mu\text{s}$	
		Full range	0.05			0.05			
V_n Equivalent input noise voltage	$f = 10\text{ Hz}$ $f = 1\text{ kHz}$	25°C		36			36	$\text{nV}/\sqrt{\text{Hz}}$	
		25°C		19			19		
$V_{N(PP)}$ Peak-to-peak equivalent input noise voltage	$f = 0.1\text{ Hz}$ to 1 Hz $f = 0.1\text{ Hz}$ to 10 Hz	25°C		0.7			0.7	μV	
		25°C		1.1			1.1		
I_n Equivalent input noise current		25°C		0.6			0.6	$\text{fA}/\sqrt{\text{Hz}}$	
THD + N Total harmonic distortion plus noise	$V_O = 0.5\text{ V}$ to 2.5 V , $f = 20\text{ kHz}$, $R_L = 50\text{ k}\Omega$ ‡	25°C	$A_V = 1$		0.2%		0.2%		
			$A_V = 10$		1%		1%		
Gain-bandwidth product	$f = 50\text{ kHz}$, $C_L = 100\text{ pF}$ ‡	$R_L = 50\text{ k}\Omega$ ‡, 25°C		0.2			0.2	MHz	
BOM Maximum output-swing bandwidth	$V_{O(PP)} = 2\text{ V}$, $R_L = 50\text{ k}\Omega$ ‡, $A_V = 1$, $C_L = 100\text{ pF}$ ‡	25°C		30			30	kHz	
ϕ_m Phase margin at unity gain	$R_L = 50\text{ k}\Omega$ ‡, $C_L = 100\text{ pF}$ ‡	25°C		63°			63°		
Gain margin		25°C		15			15	dB	

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

‡ Referenced to 2.5 V



TYPICAL CHARACTERISTICS

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TYPICAL CHARACTERISTICS

**DISTRIBUTION OF TLV2252
 INPUT OFFSET VOLTAGE**

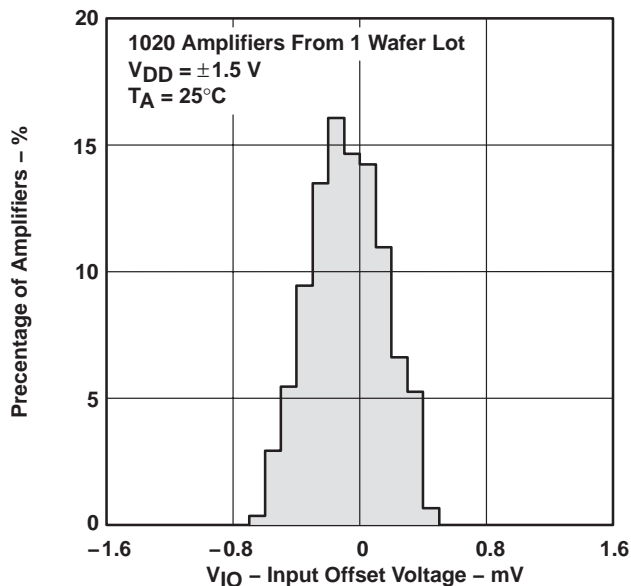


Figure 2

**DISTRIBUTION OF TLV2252
 INPUT OFFSET VOLTAGE**

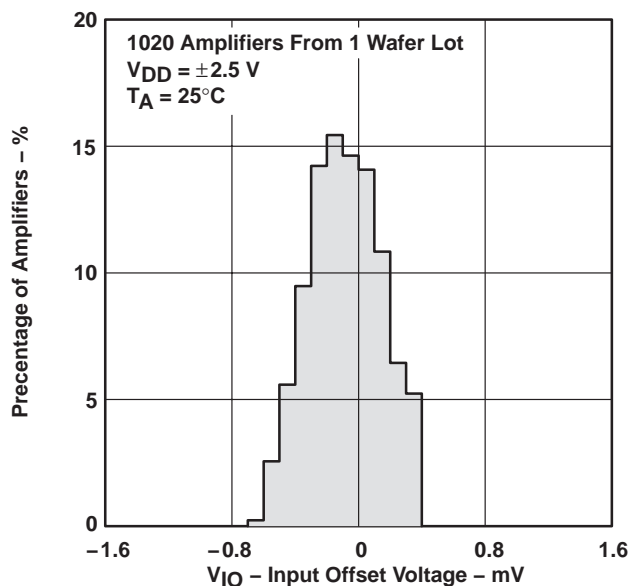


Figure 3

**DISTRIBUTION OF TLV2254
 INPUT OFFSET VOLTAGE**

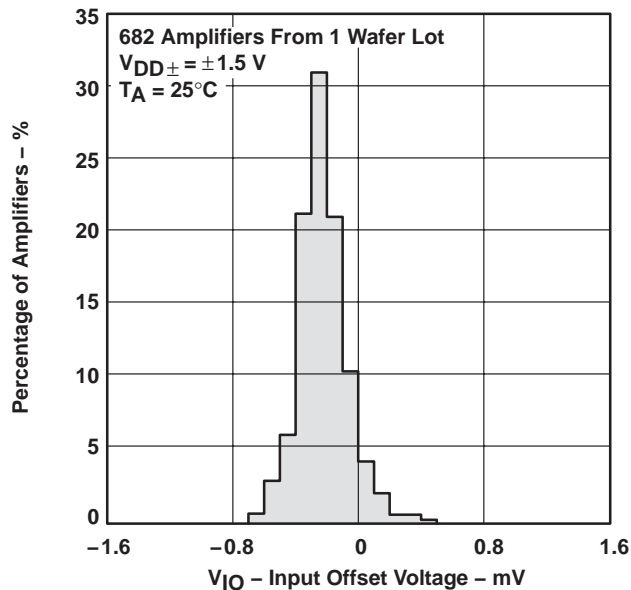


Figure 4

**DISTRIBUTION OF TLV2254
 INPUT OFFSET VOLTAGE**

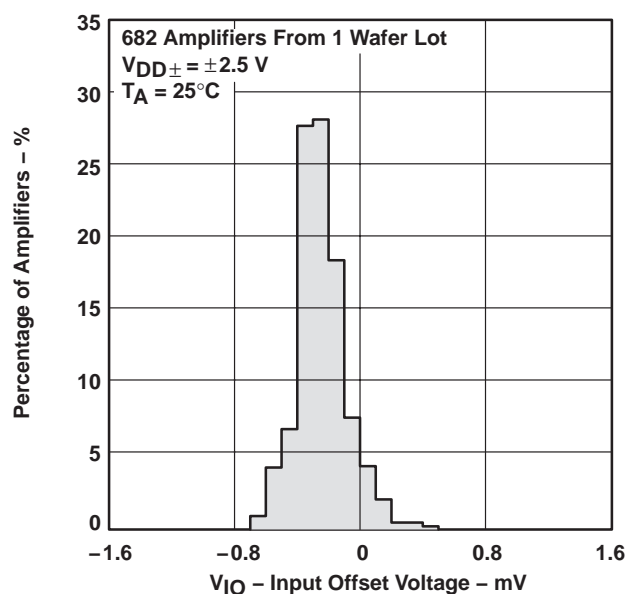


Figure 5



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TYPICAL CHARACTERISTICS

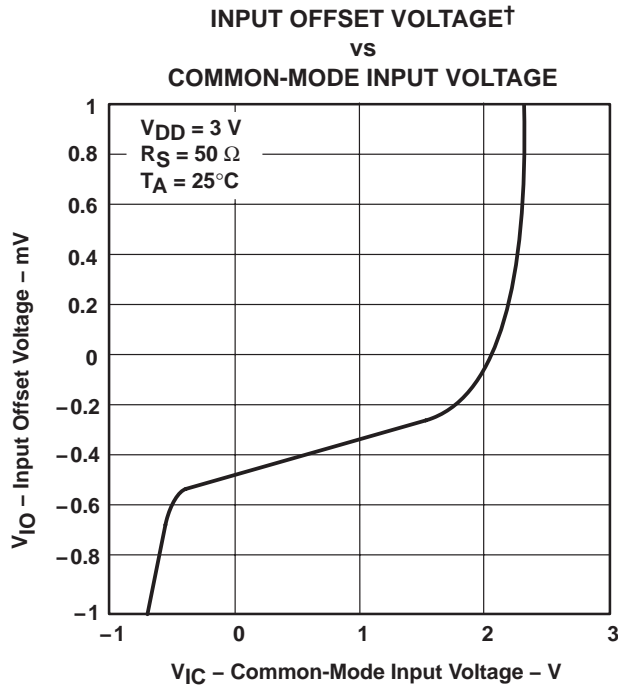


Figure 6

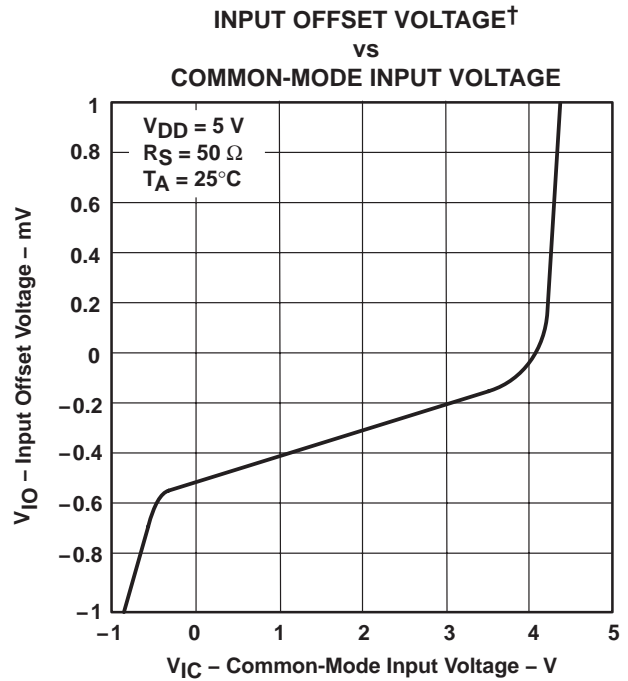


Figure 7

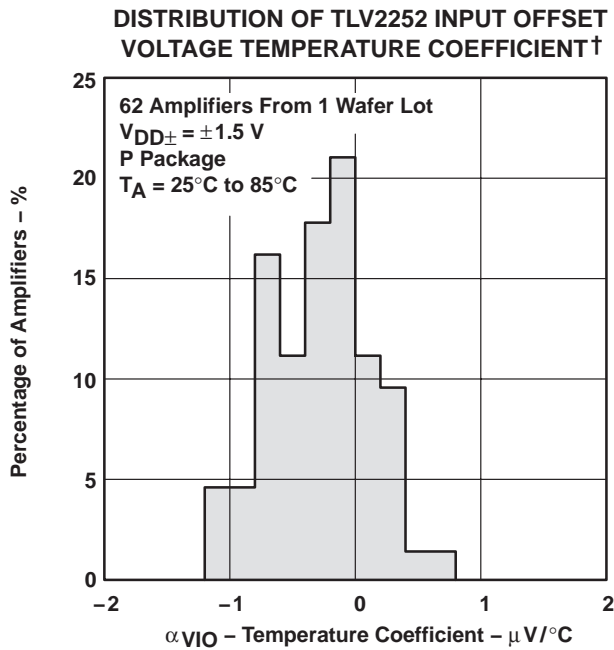


Figure 8

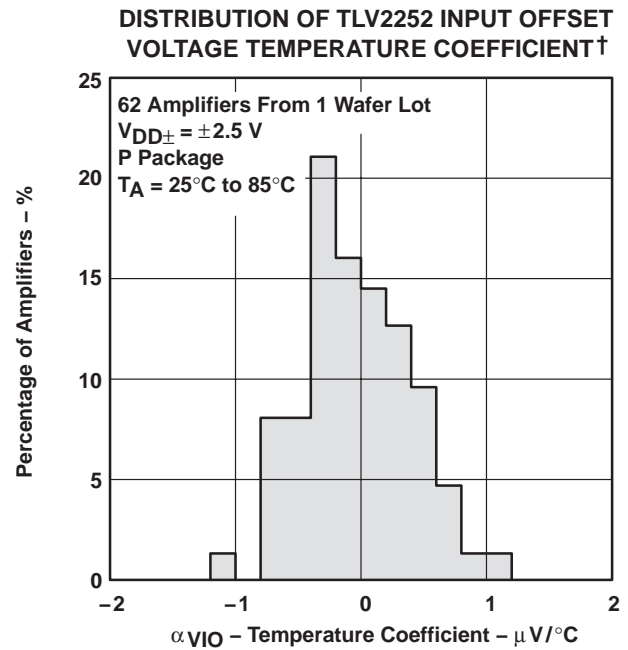


Figure 9

† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.

TYPICAL CHARACTERISTICS

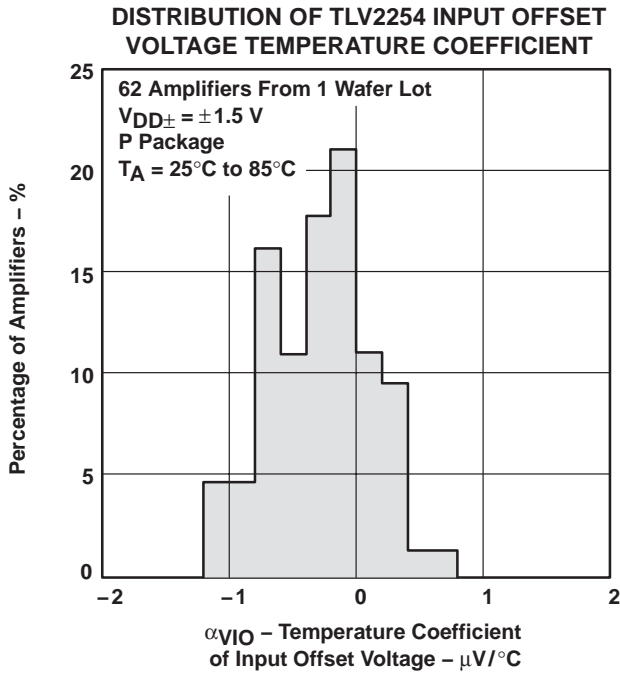


Figure 10

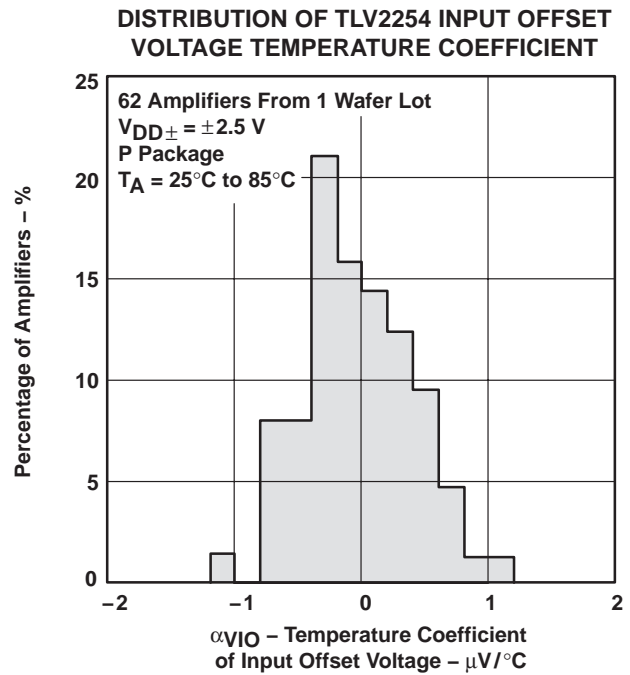


Figure 11

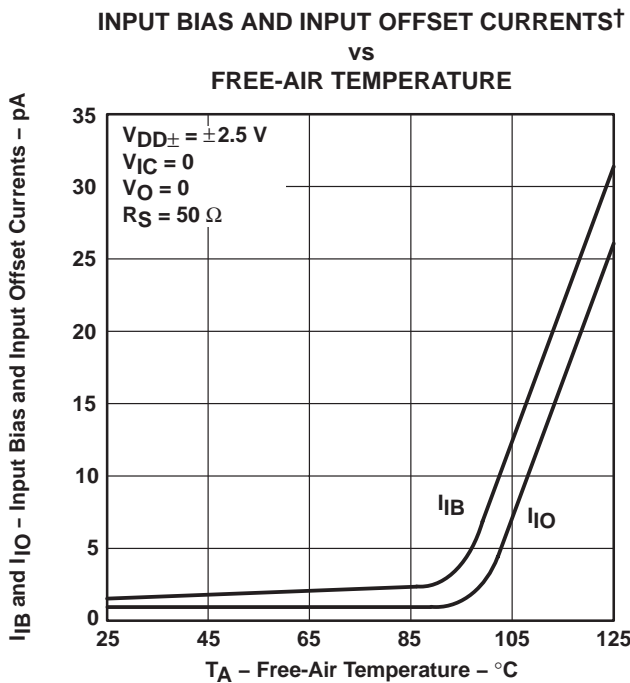


Figure 12

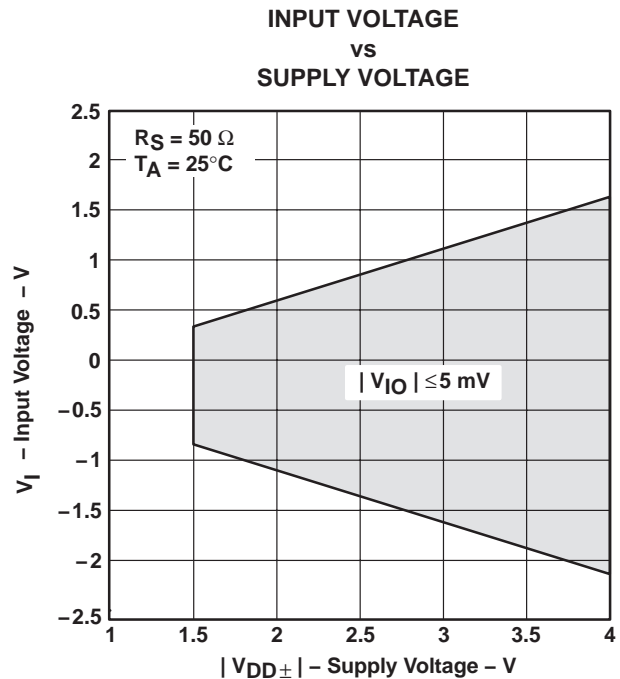
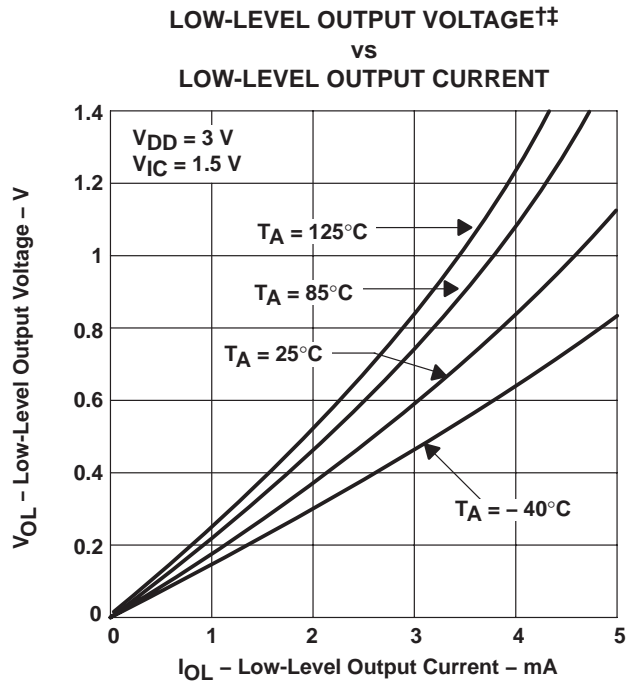
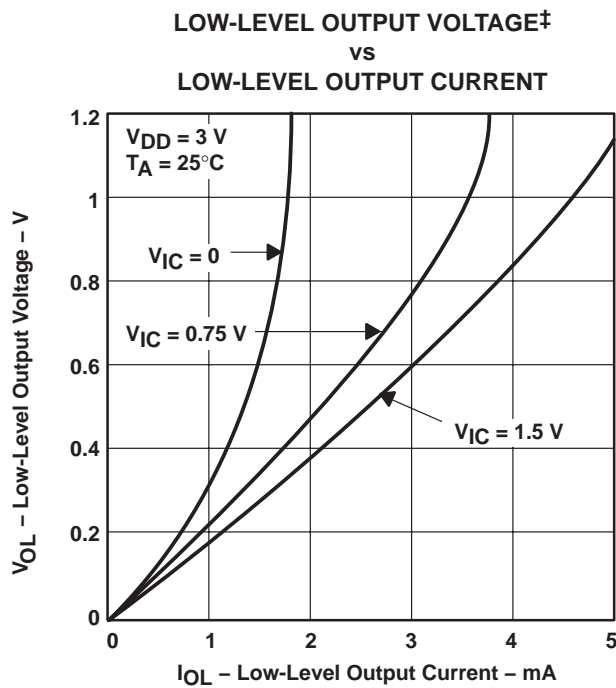
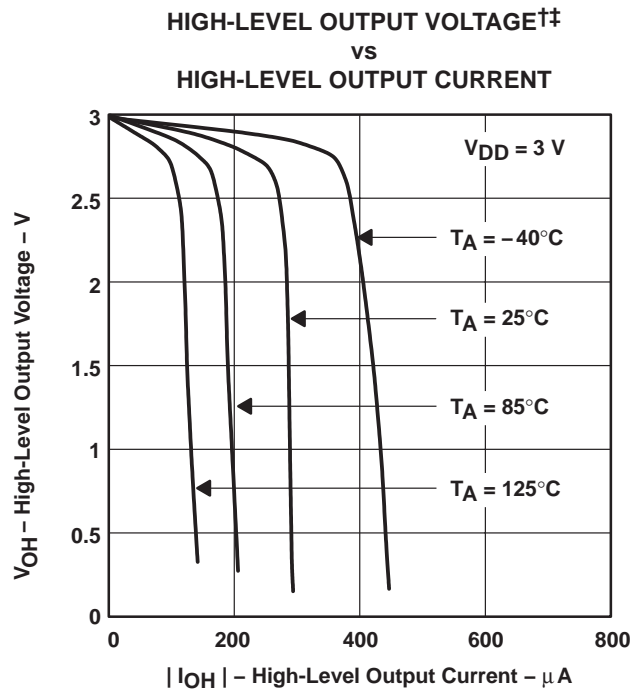
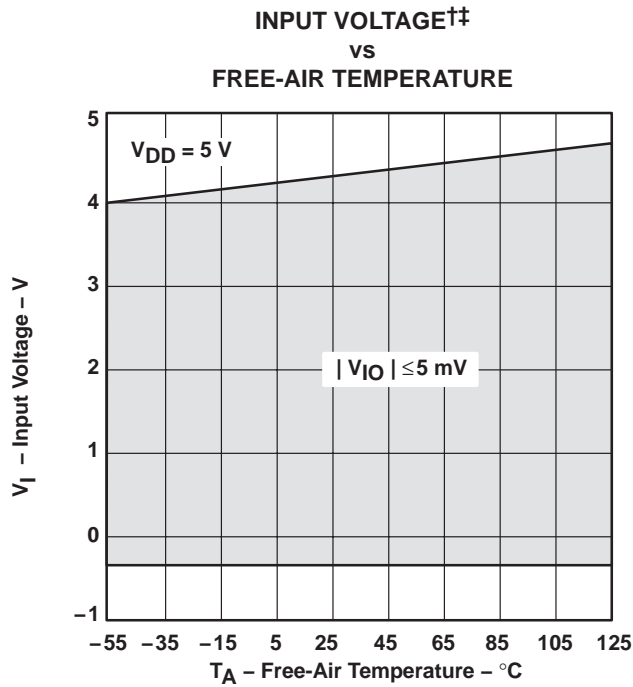


Figure 13

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

TYPICAL CHARACTERISTICS



† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.
 †† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.

TYPICAL CHARACTERISTICS

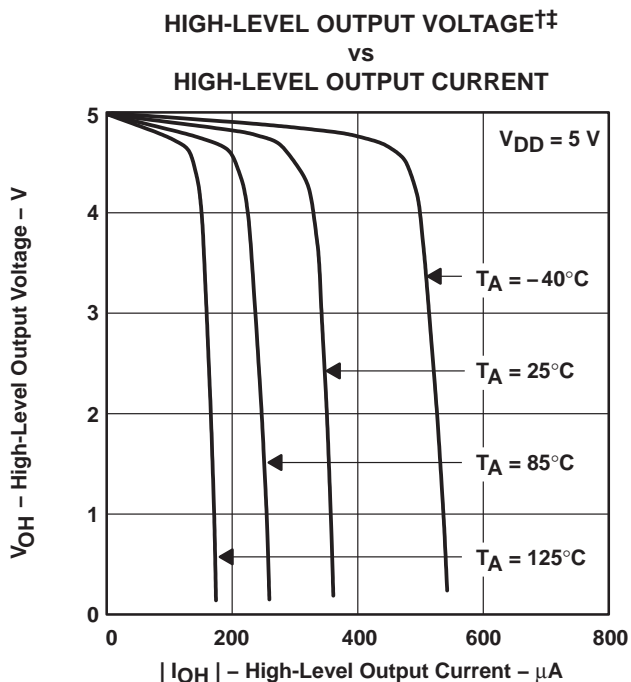


Figure 18

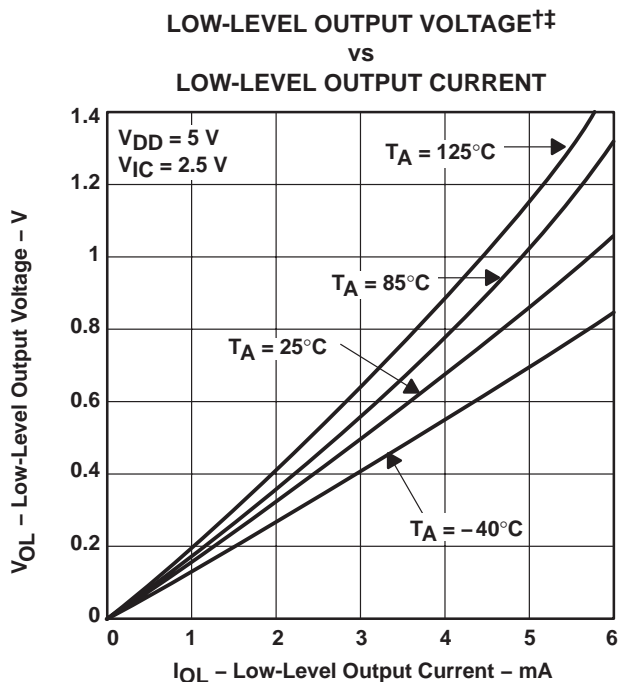


Figure 19

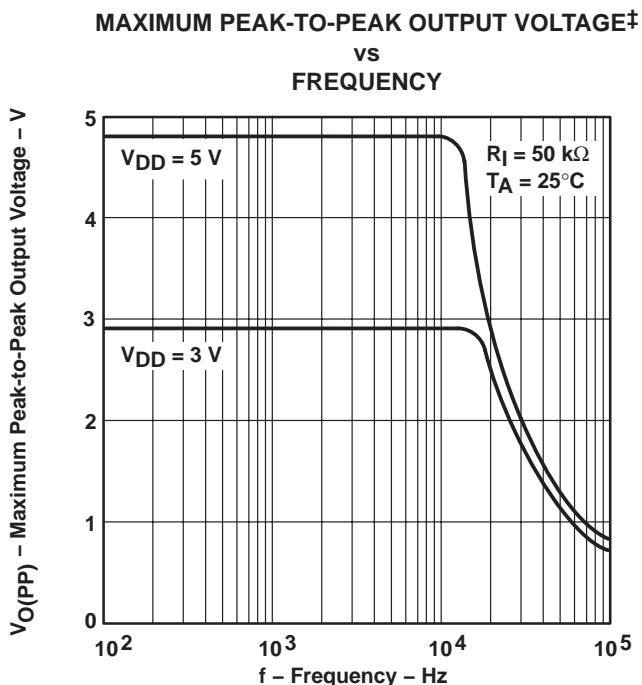


Figure 20

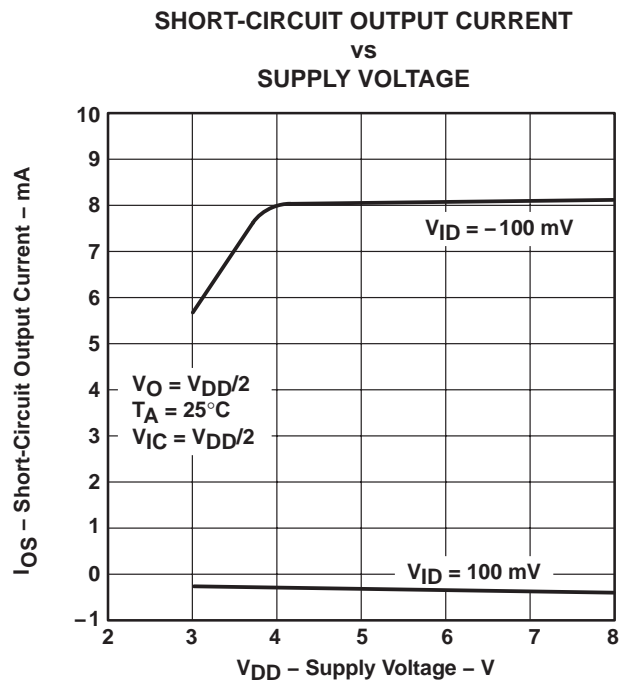


Figure 21

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.
 ‡ For all curves where $V_{DD} = 5 V$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3 V$, all loads are referenced to 1.5 V.

TYPICAL CHARACTERISTICS

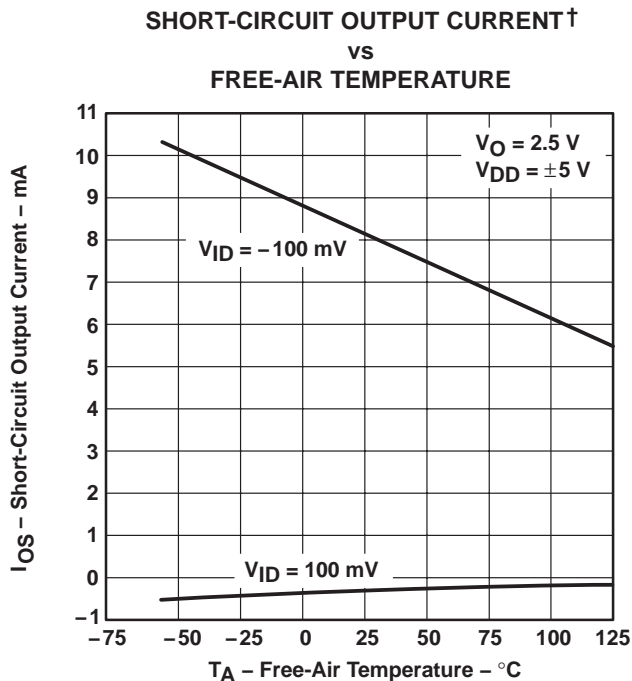


Figure 22

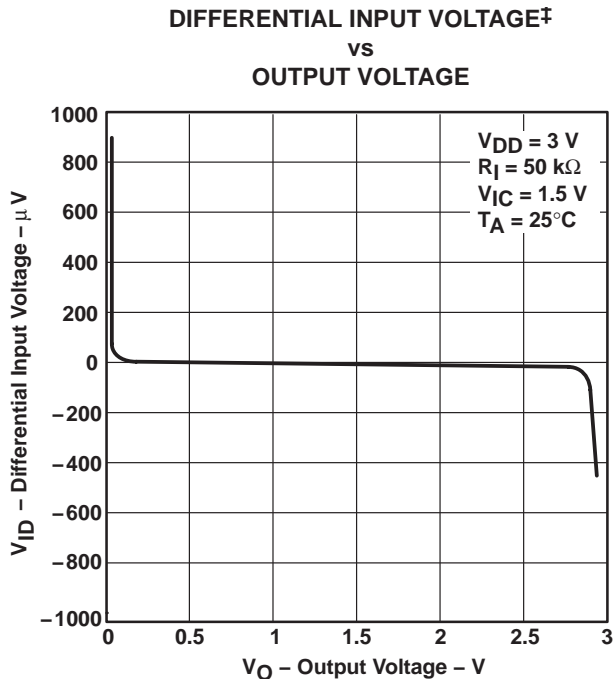


Figure 23

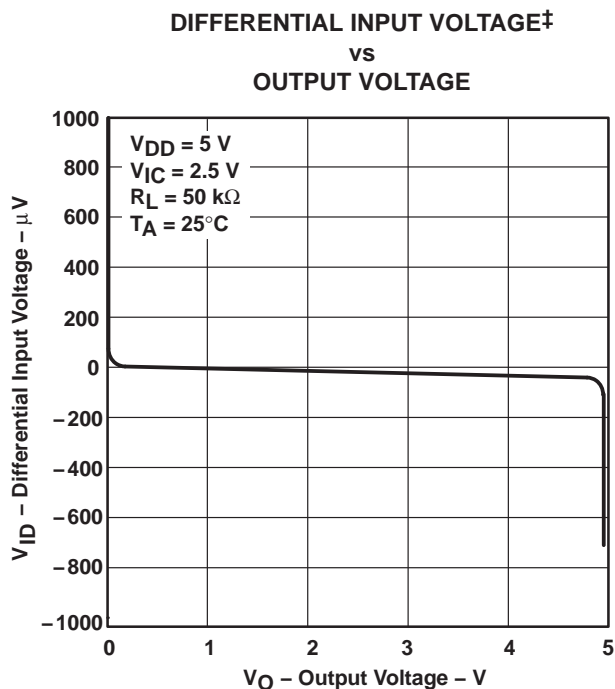


Figure 24

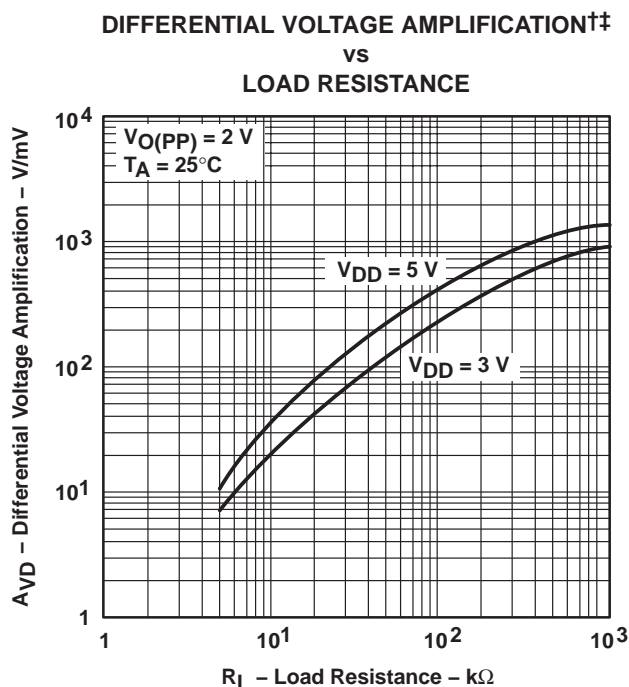


Figure 25

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.
 ‡ For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.

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TYPICAL CHARACTERISTICS

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

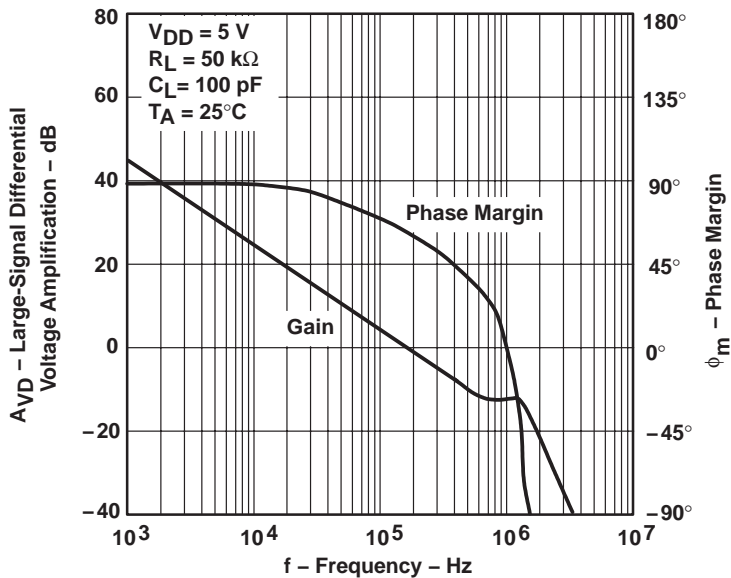


Figure 26

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

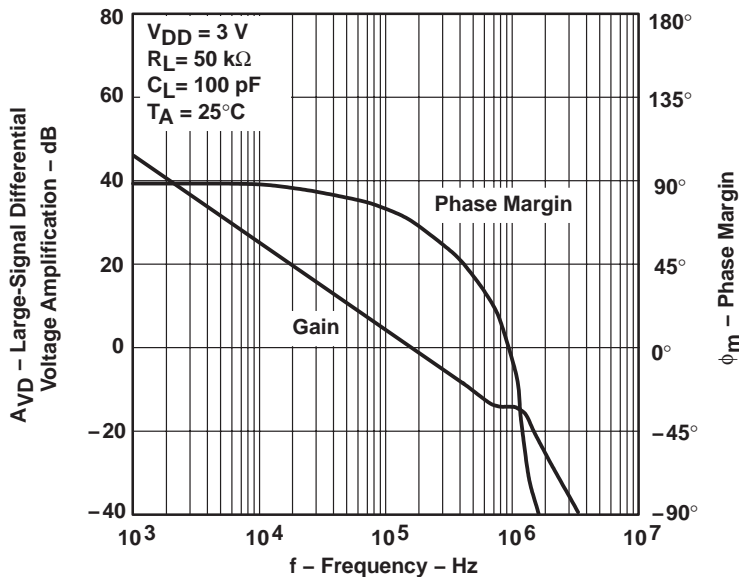


Figure 27

† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.



TYPICAL CHARACTERISTICS

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

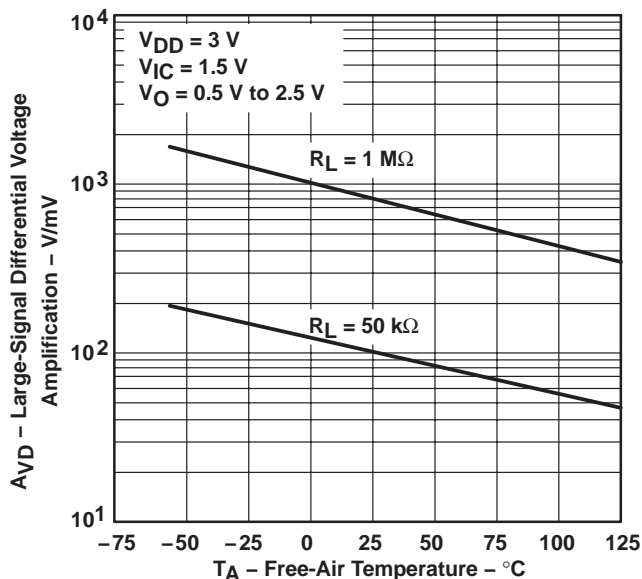


Figure 28

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

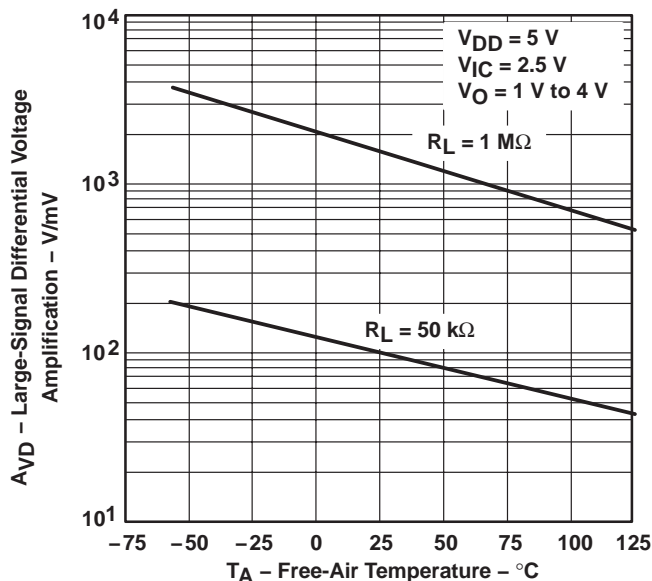


Figure 29

OUTPUT IMPEDANCE‡
 vs
 FREQUENCY

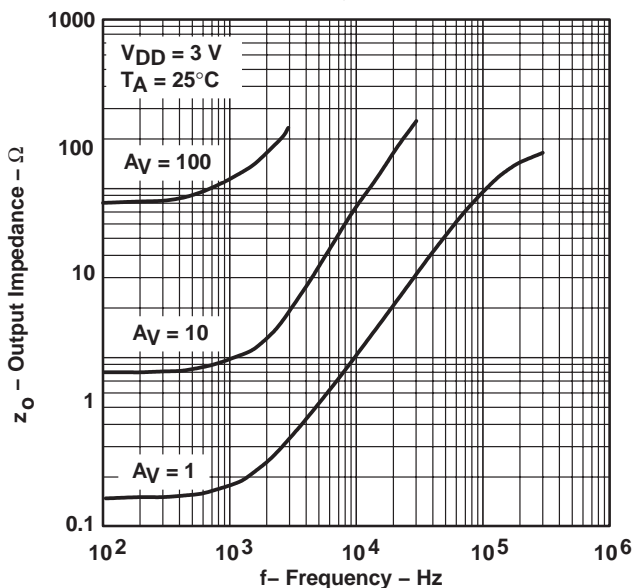


Figure 30

OUTPUT IMPEDANCE‡
 vs
 FREQUENCY

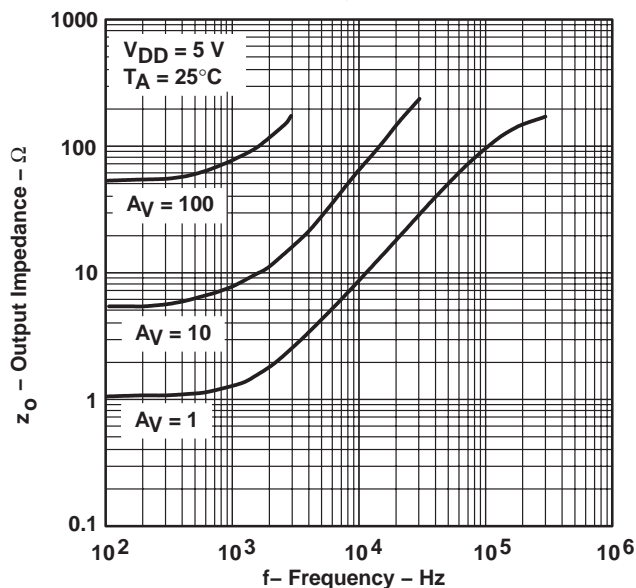


Figure 31

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

‡ For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.

TYPICAL CHARACTERISTICS

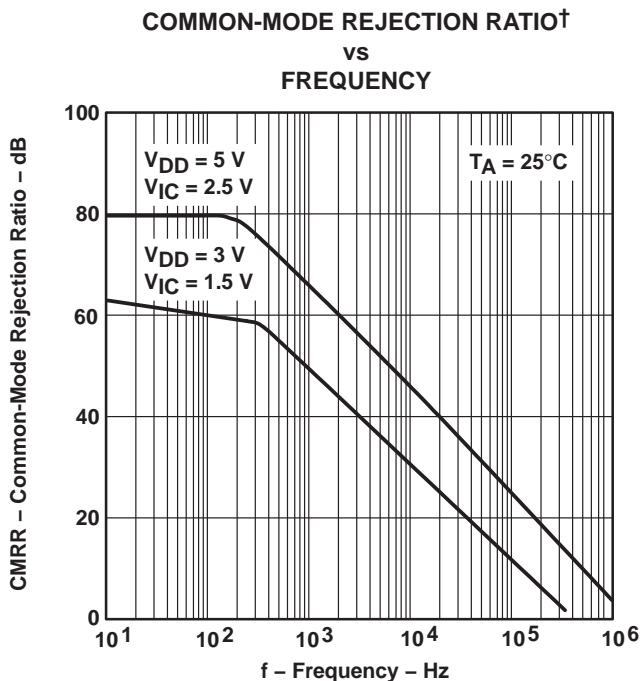


Figure 32

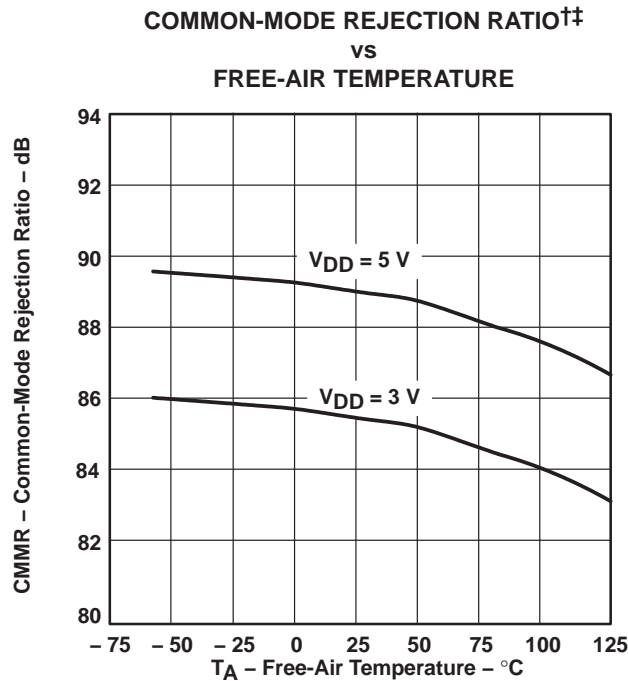


Figure 33

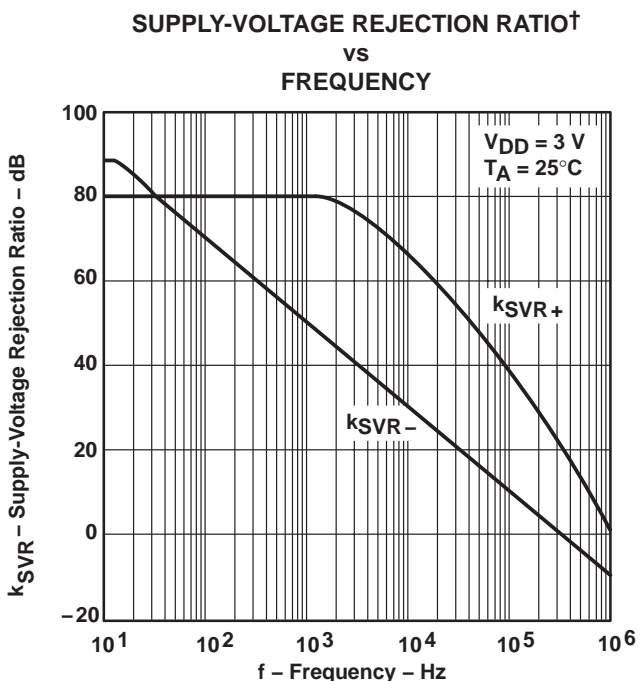


Figure 34

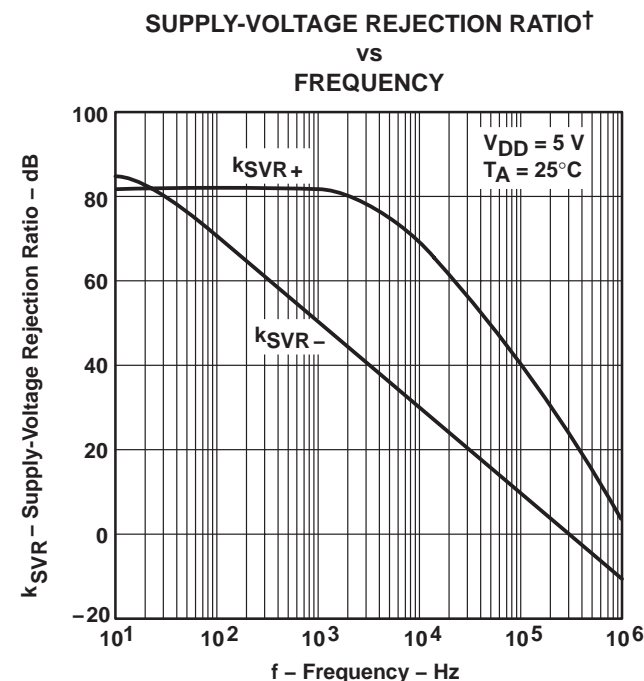
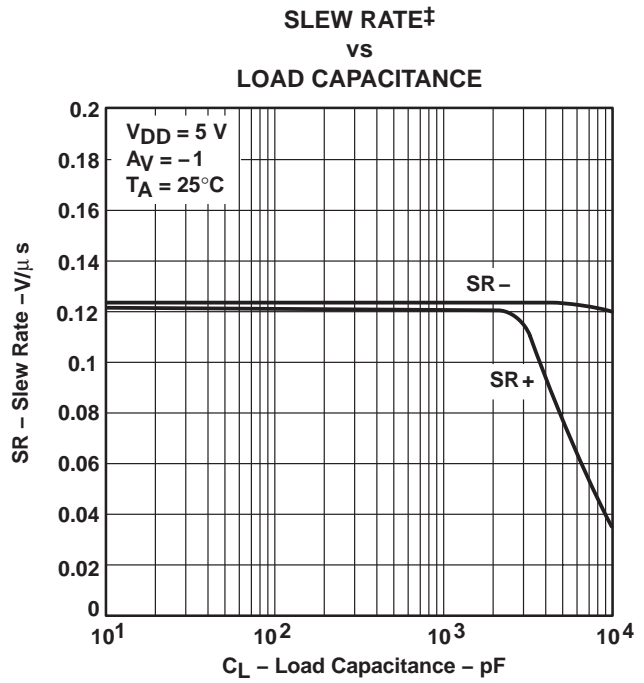
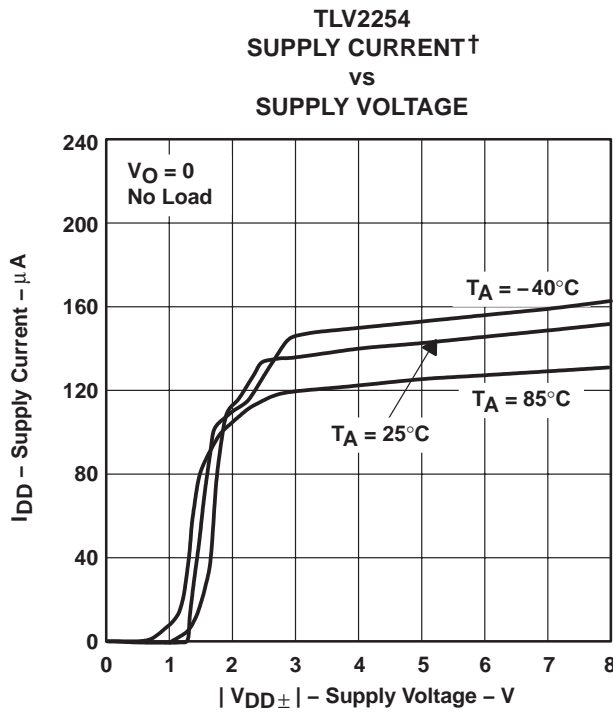
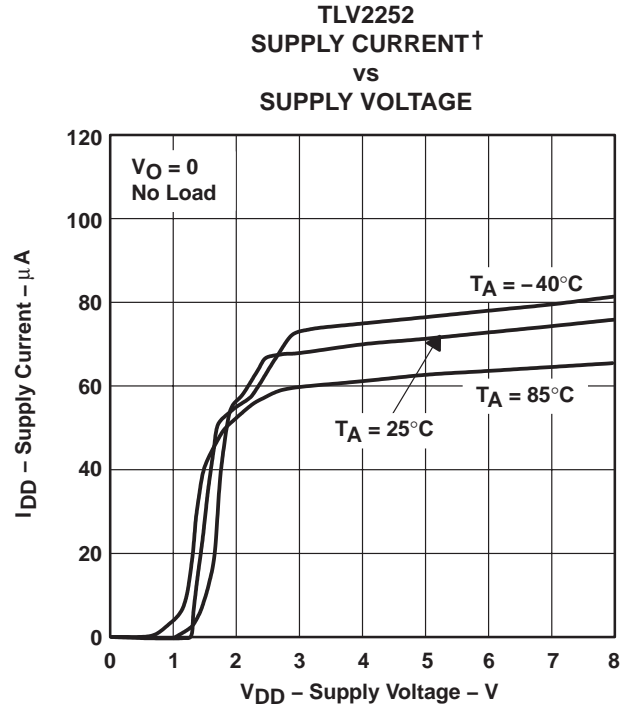
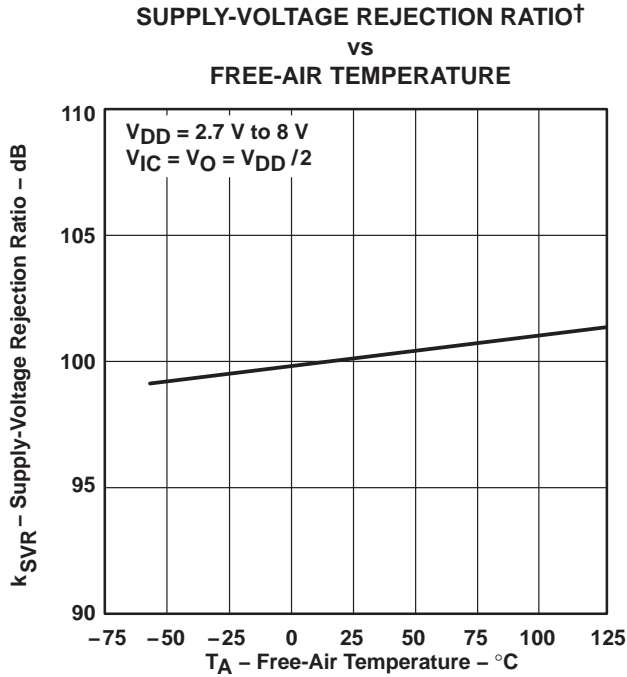


Figure 35

† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.
 ‡ Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS



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

‡ For all curves where $V_{DD} = 5$ V, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3$ V, all loads are referenced to 1.5 V.

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TYPICAL CHARACTERISTICS

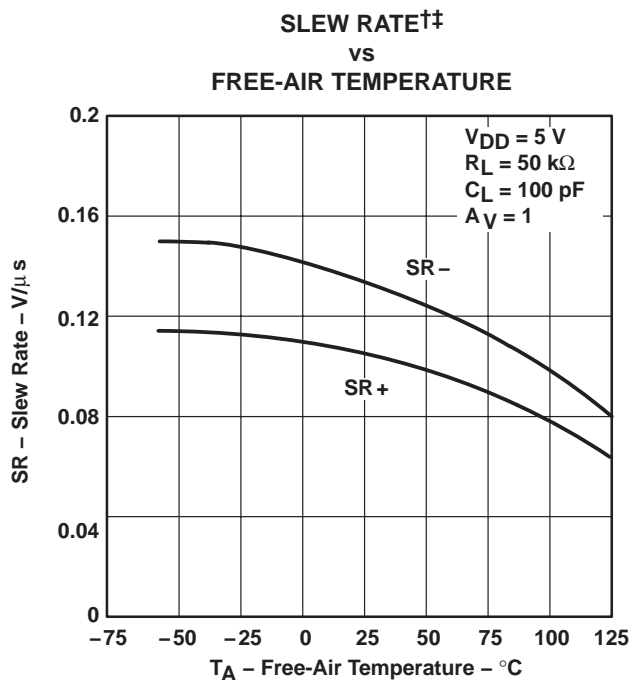


Figure 40

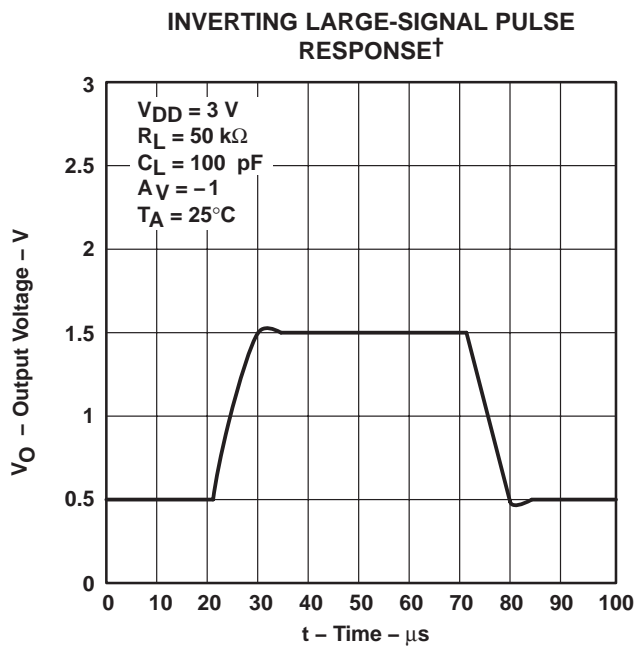


Figure 41

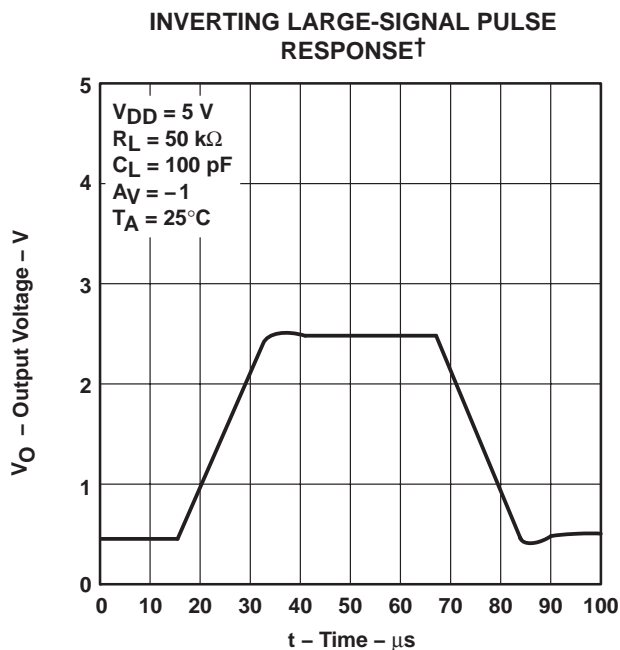


Figure 42

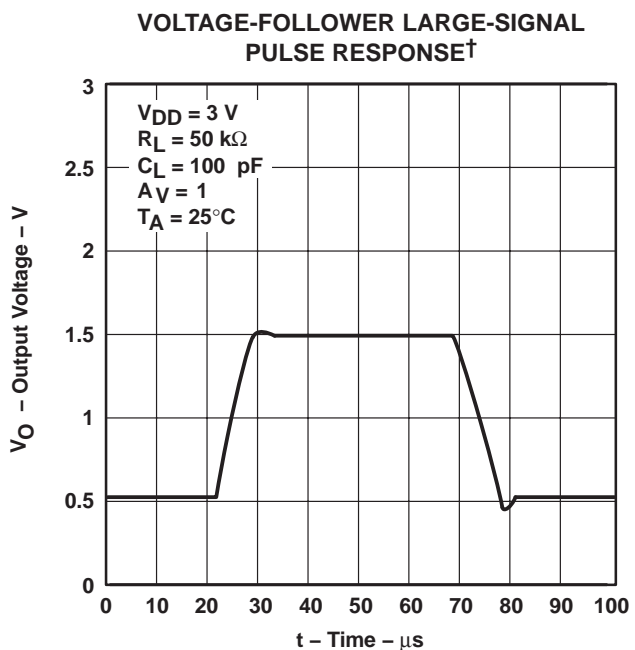


Figure 43

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

†† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.



TYPICAL CHARACTERISTICS

VOLTAGE-FOLLOWER LARGE-SIGNAL PULSE RESPONSE†

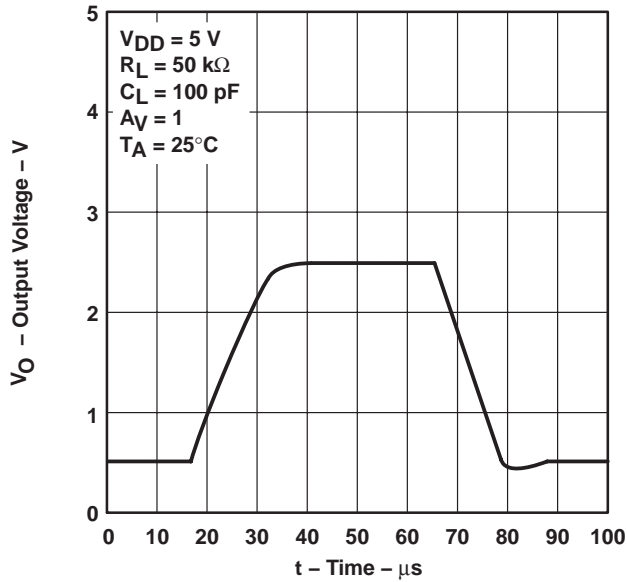


Figure 44

INVERTING SMALL-SIGNAL PULSE RESPONSE†

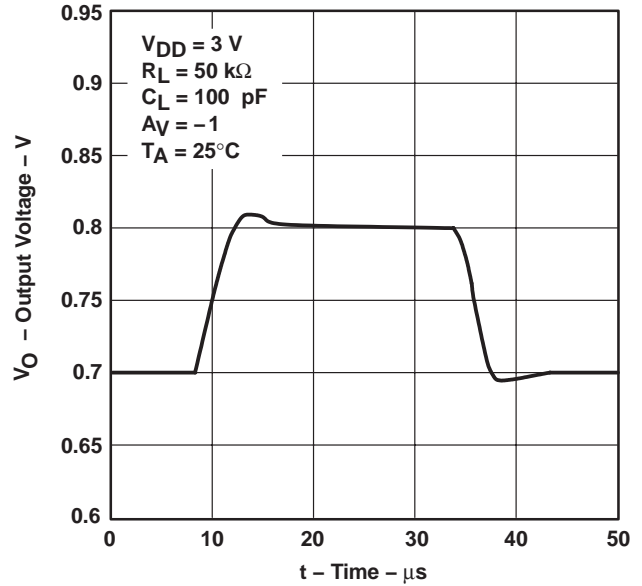


Figure 45

INVERTING SMALL-SIGNAL PULSE RESPONSE†

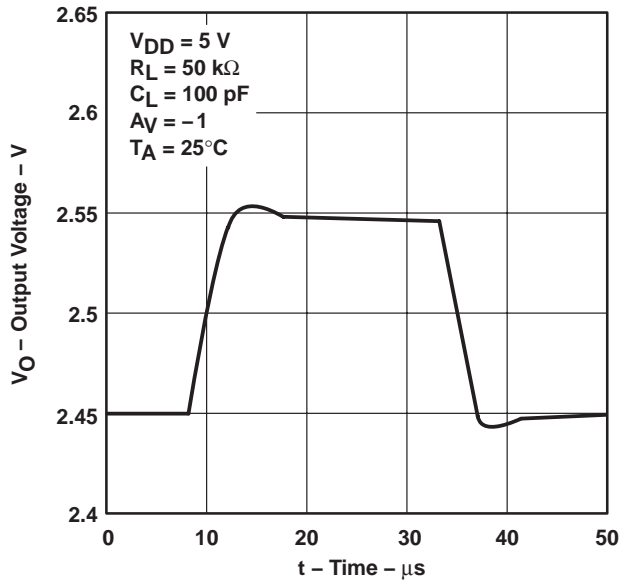


Figure 46

VOLTAGE-FOLLOWER SMALL-SIGNAL PULSE RESPONSE†

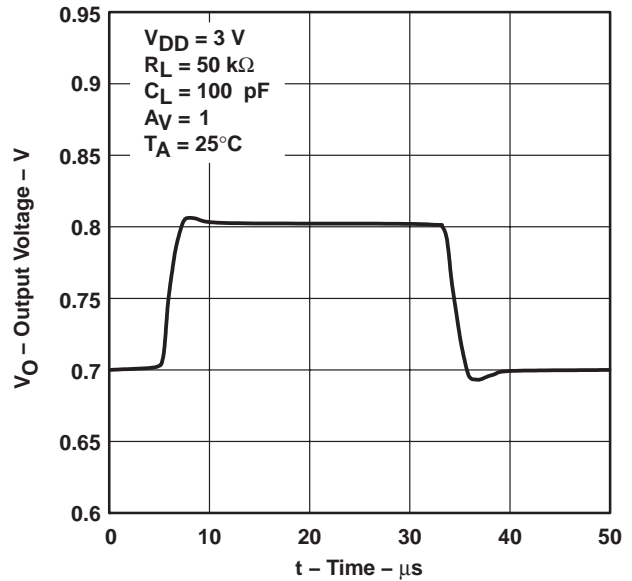


Figure 47

† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.

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TYPICAL CHARACTERISTICS

VOLTAGE-FOLLOWER SMALL-SIGNAL PULSE RESPONSE†

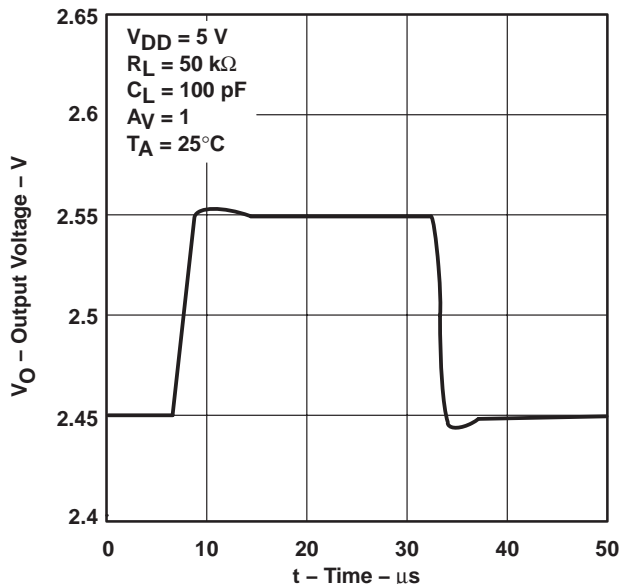


Figure 48

EQUIVALENT INPUT NOISE VOLTAGE† VS FREQUENCY

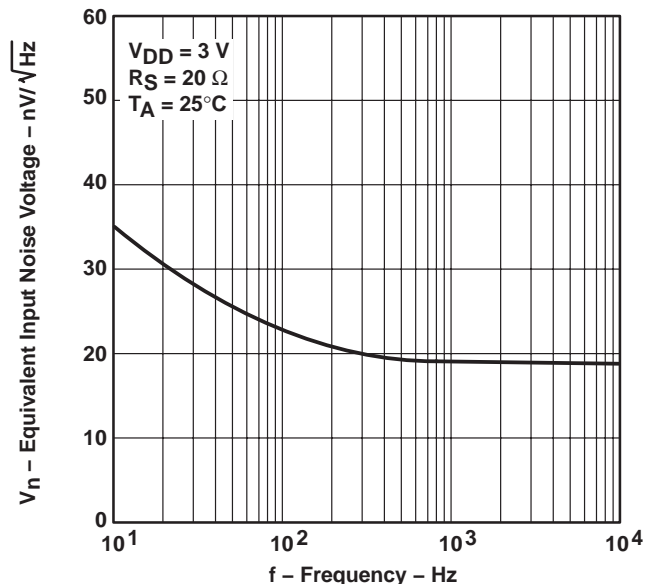


Figure 49

EQUIVALENT INPUT NOISE VOLTAGE† VS FREQUENCY

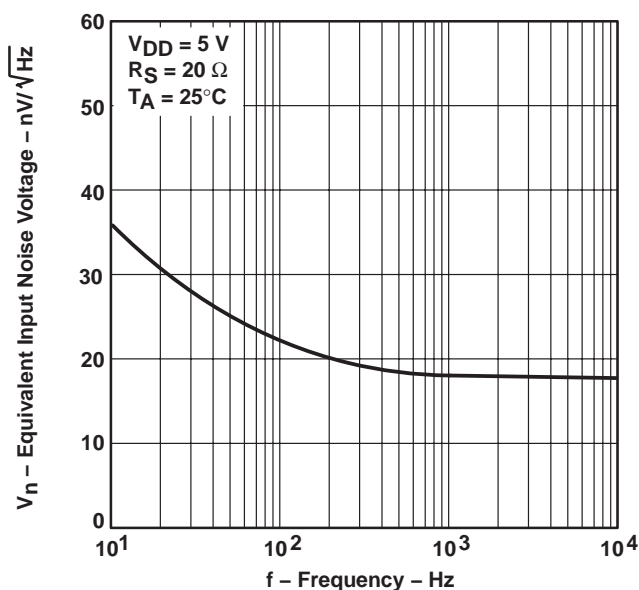


Figure 50

INPUT NOISE VOLTAGE OVER A 10-SECOND PERIOD†

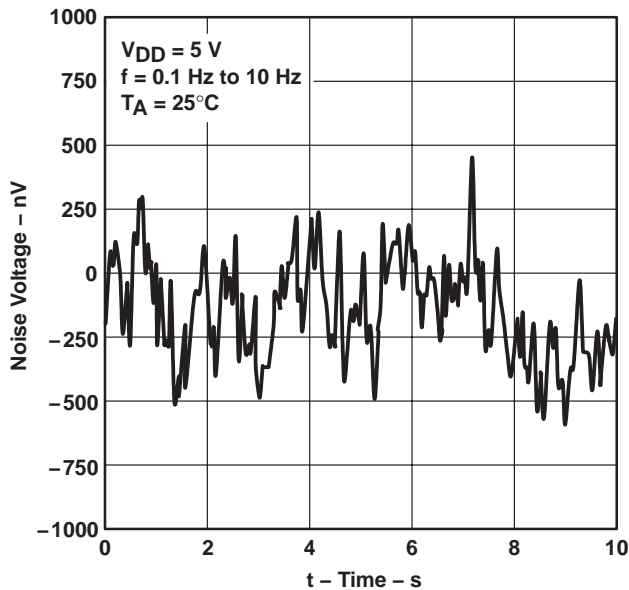


Figure 51

† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.



TYPICAL CHARACTERISTICS

INTEGRATED NOISE VOLTAGE†
 vs
 FREQUENCY

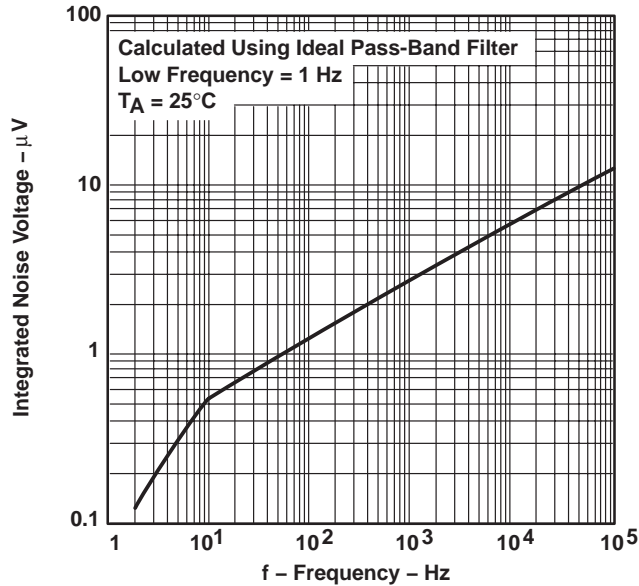


Figure 52

TOTAL HARMONIC DISTORTION PLUS NOISE‡
 vs
 FREQUENCY

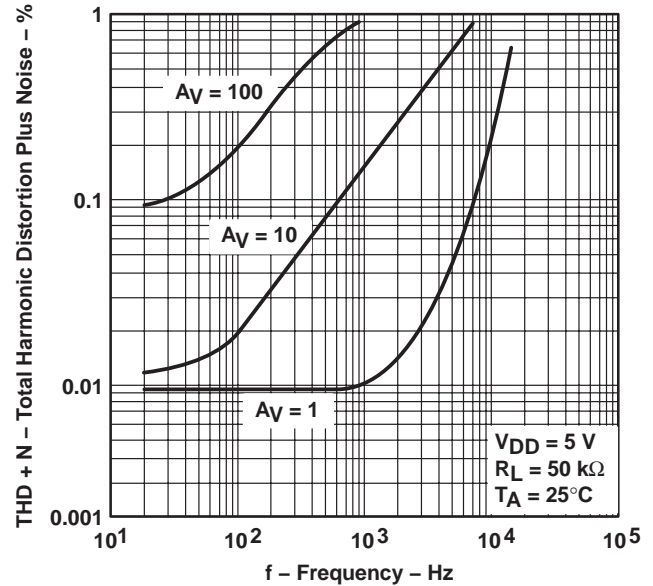


Figure 53

GAIN-BANDWIDTH PRODUCT
 vs
 SUPPLY VOLTAGE

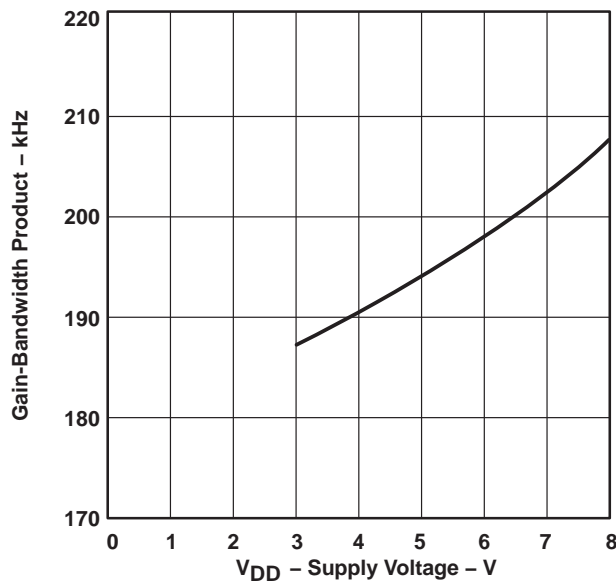


Figure 54

GAIN-BANDWIDTH PRODUCT‡‡
 vs
 FREE-AIR TEMPERATURE

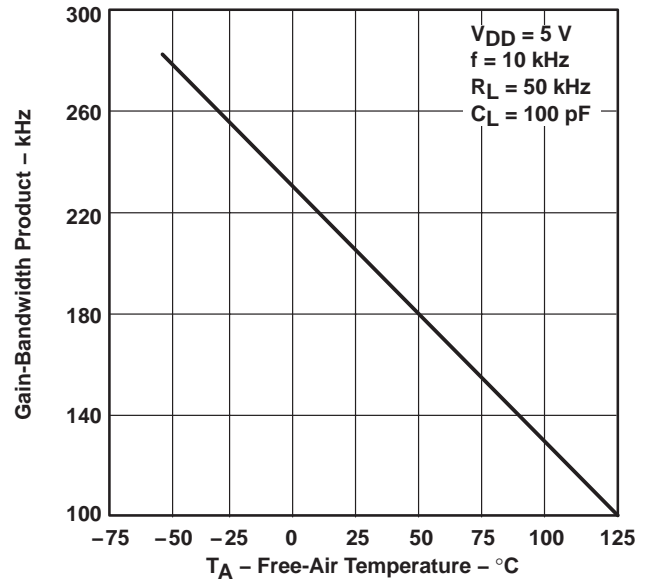


Figure 55

† For all curves where $V_{DD} = 5\text{ V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\text{ V}$, all loads are referenced to 1.5 V.

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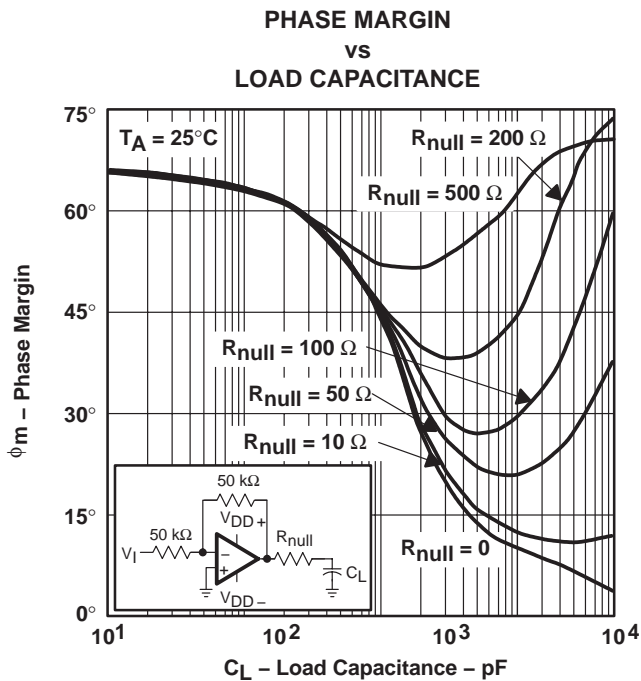


Figure 56

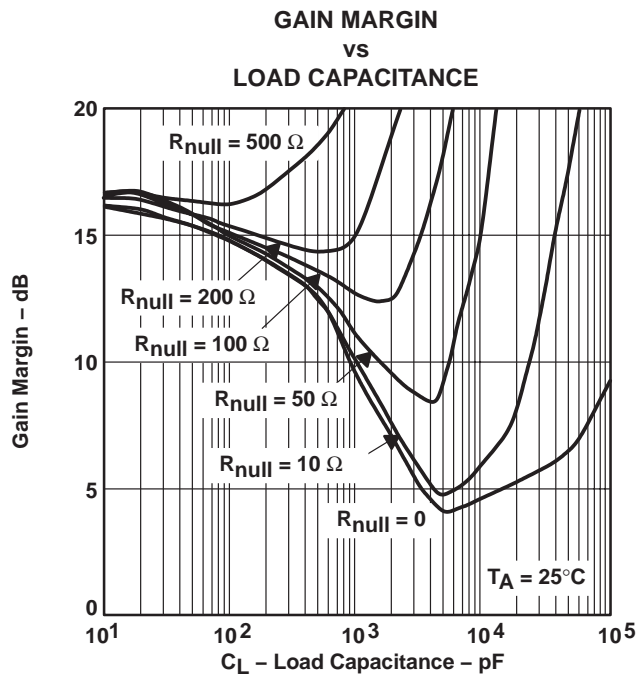


Figure 57

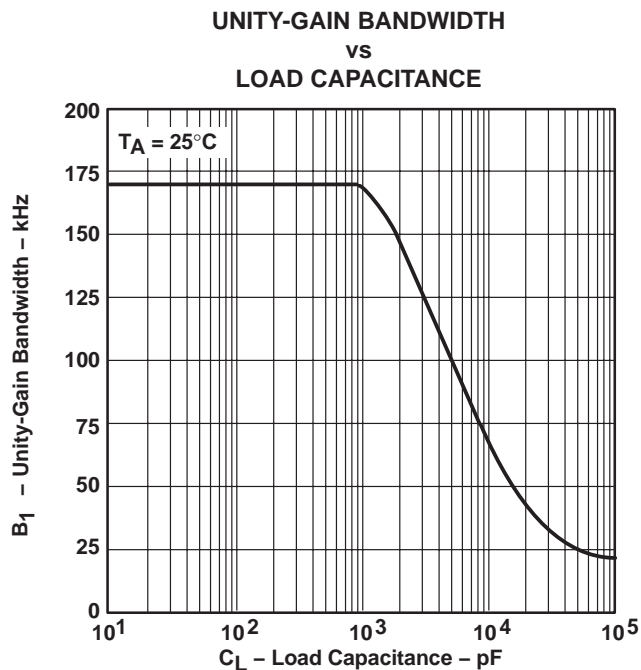
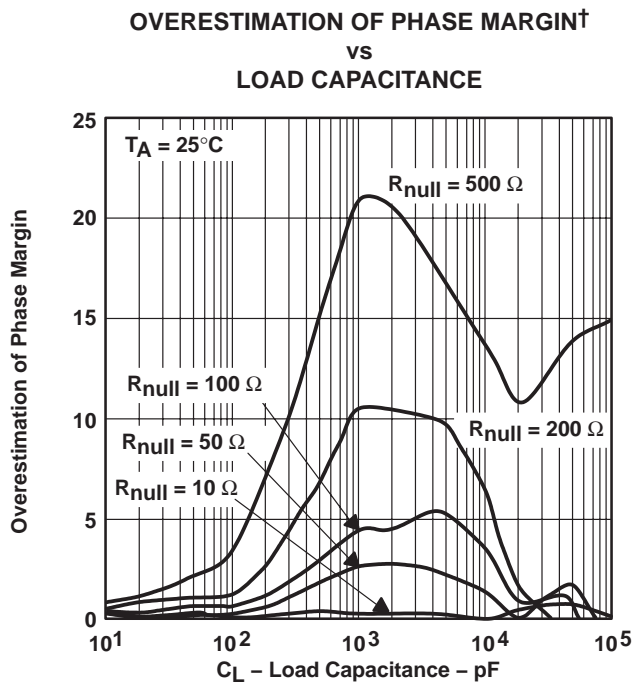


Figure 58



† See application information

Figure 59

† For all curves where $V_{DD} = 5\ \text{V}$, all loads are referenced to 2.5 V. For all curves where $V_{DD} = 3\ \text{V}$, all loads are referenced to 1.5 V.

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

APPLICATION INFORMATION

driving large capacitive loads

The TLV2252 is designed to drive larger capacitive loads than most CMOS operational amplifiers. Figure 56 and Figure 57 illustrate its ability to drive loads up to 1000 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 60) improves the gain and phase margins when driving large capacitive loads. Figure 55 and Figure 56 show the effects of adding series resistances of 10 Ω , 50 Ω , 100 Ω , 200 Ω , and 500 Ω . The addition of this series resistor has two effects: the first adds a zero to the transfer function and the second 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.

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

Where :

- $\Delta\phi_{m1}$ = 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 58). To use equation 1, UGBW must be approximated from Figure 58.

Using equation 1 alone overestimates the improvement in phase margin as illustrated in Figure 59. The overestimation is caused by the decrease in the frequency of the pole associated with the load, providing additional phase shift and reducing the overall improvement in phase margin.

Using Figure 60, with equation 1 enables the designer to choose the appropriate output series resistance to optimize the design of circuits driving large capacitance loads.

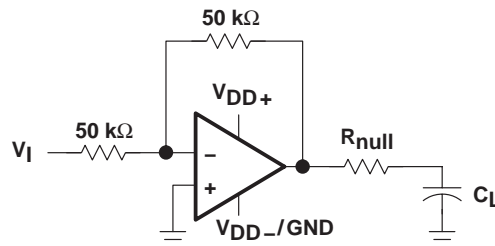


Figure 60. Series-Resistance Circuit

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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 61 are generated using the TLV2252 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).

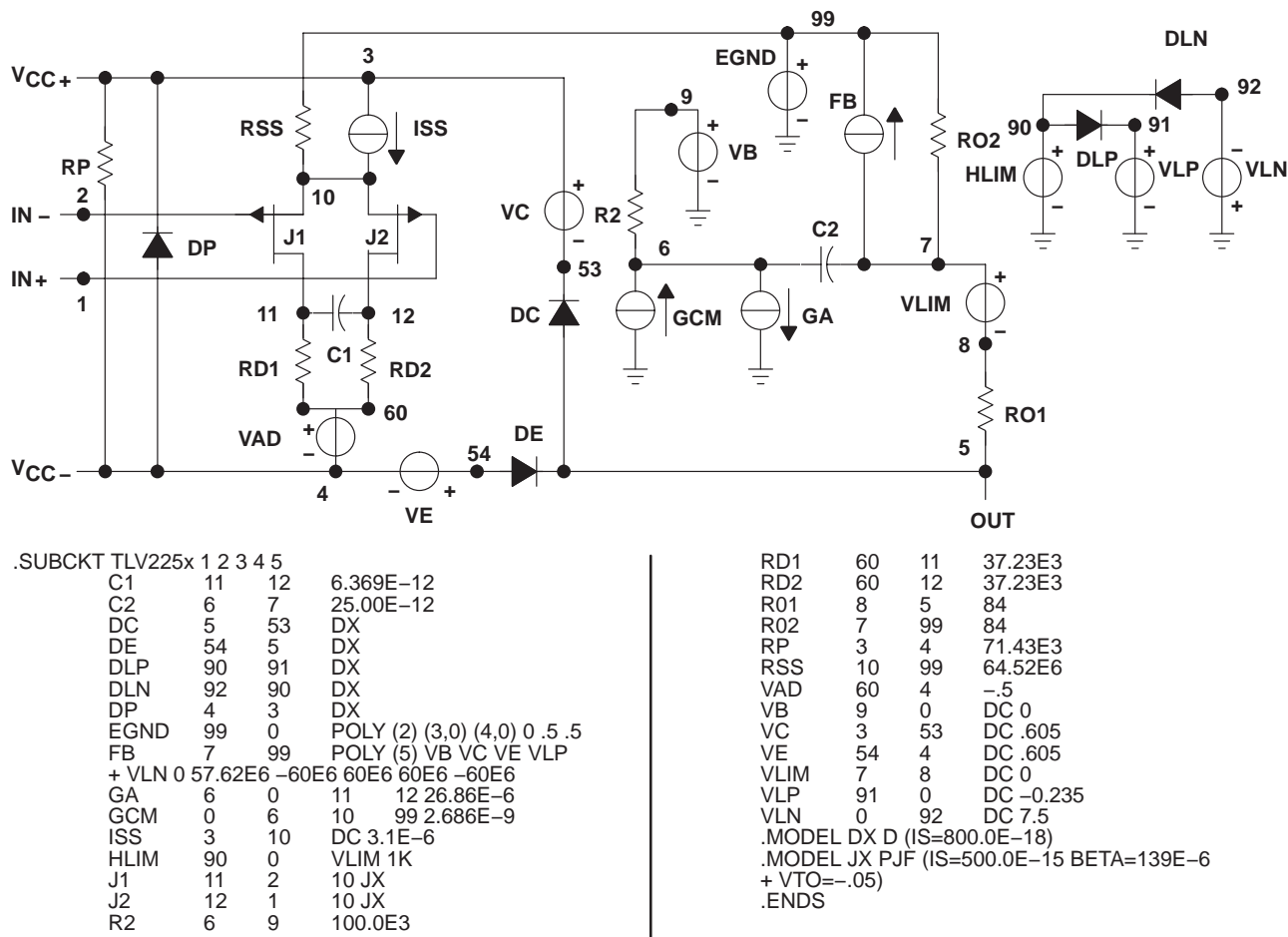


Figure 61. Boyle Macromodel and Subcircuit

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
TLV2252AQDRG4Q1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLV2252AQDRQ1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLV2252QDRG4Q1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLV2252QDRQ1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLV2254AQDRG4Q1	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLV2254AQDRQ1	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLV2254QDRG4Q1	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	
TLV2254QDRQ1	OBSOLETE	SOIC	D	14		TBD	Call TI	Call TI	

(1) 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.

(2) 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)

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



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PACKAGE OPTION ADDENDUM

6-Jan-2013

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OTHER QUALIFIED VERSIONS OF TLV2252-Q1, TLV2252A-Q1, TLV2254-Q1, TLV2254A-Q1 :

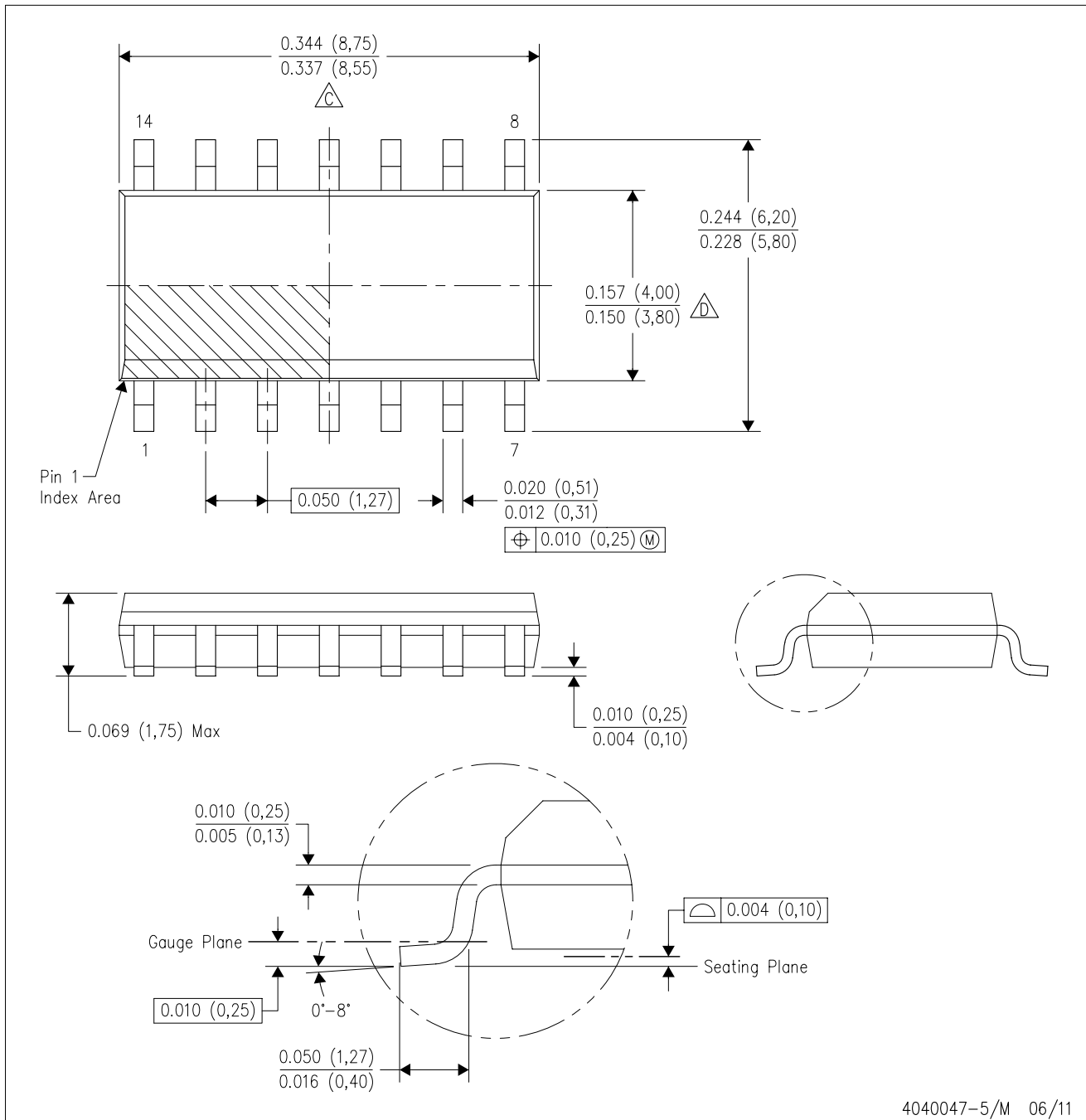
- Catalog: [TLV2252](#), [TLV2252A](#), [TLV2254](#), [TLV2254A](#)
- Enhanced Product: [TLV2252-EP](#), [TLV2252A-EP](#), [TLV2254-EP](#), [TLV2254A-EP](#)
- Military: [TLV2252M](#), [TLV2252AM](#), [TLV2254M](#), [TLV2254AM](#)

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

D (R-PDSO-G14)

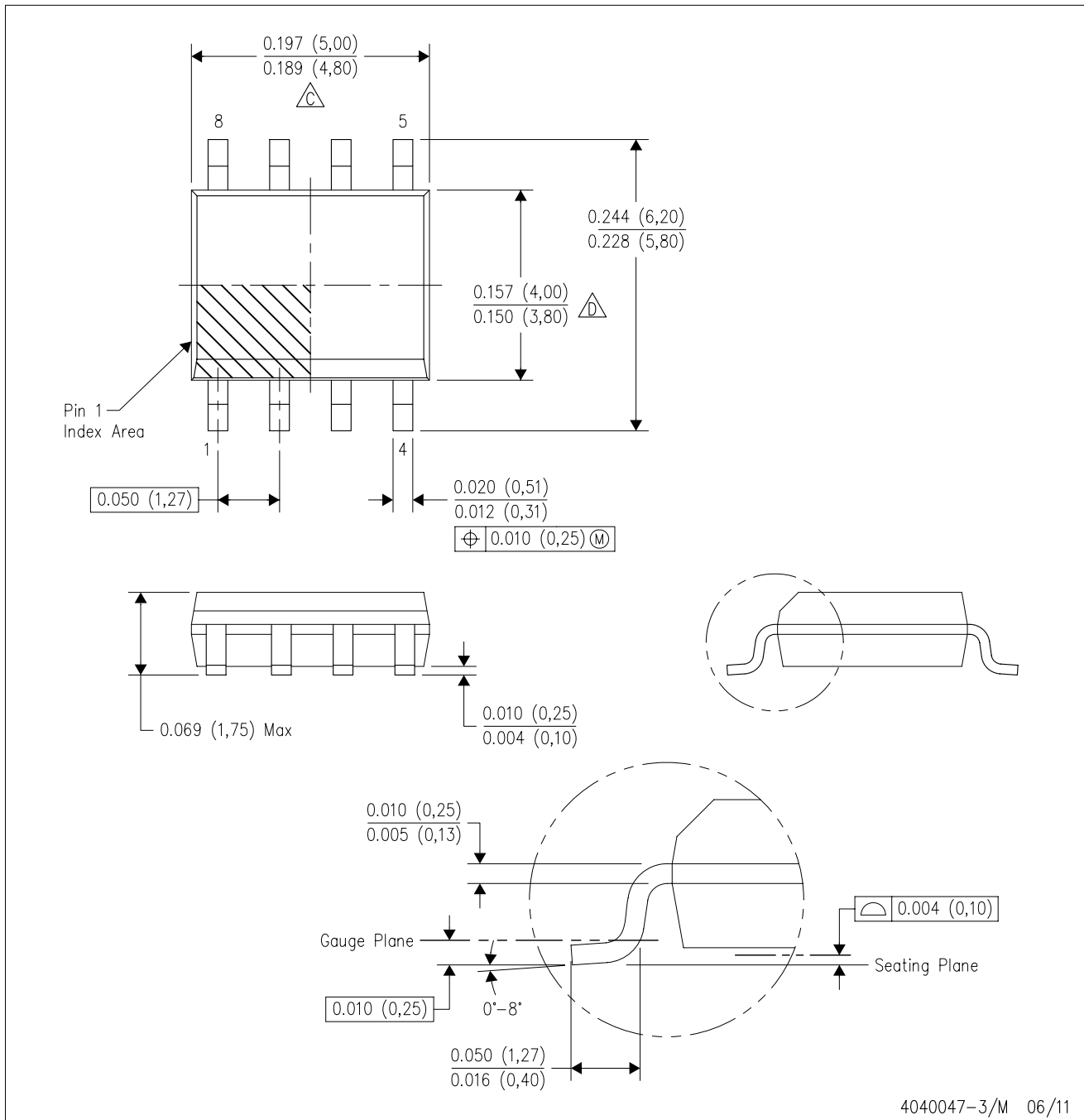
PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
 - Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
 - E. Reference JEDEC MS-012 variation AB.

D (R-PDSO-G8)

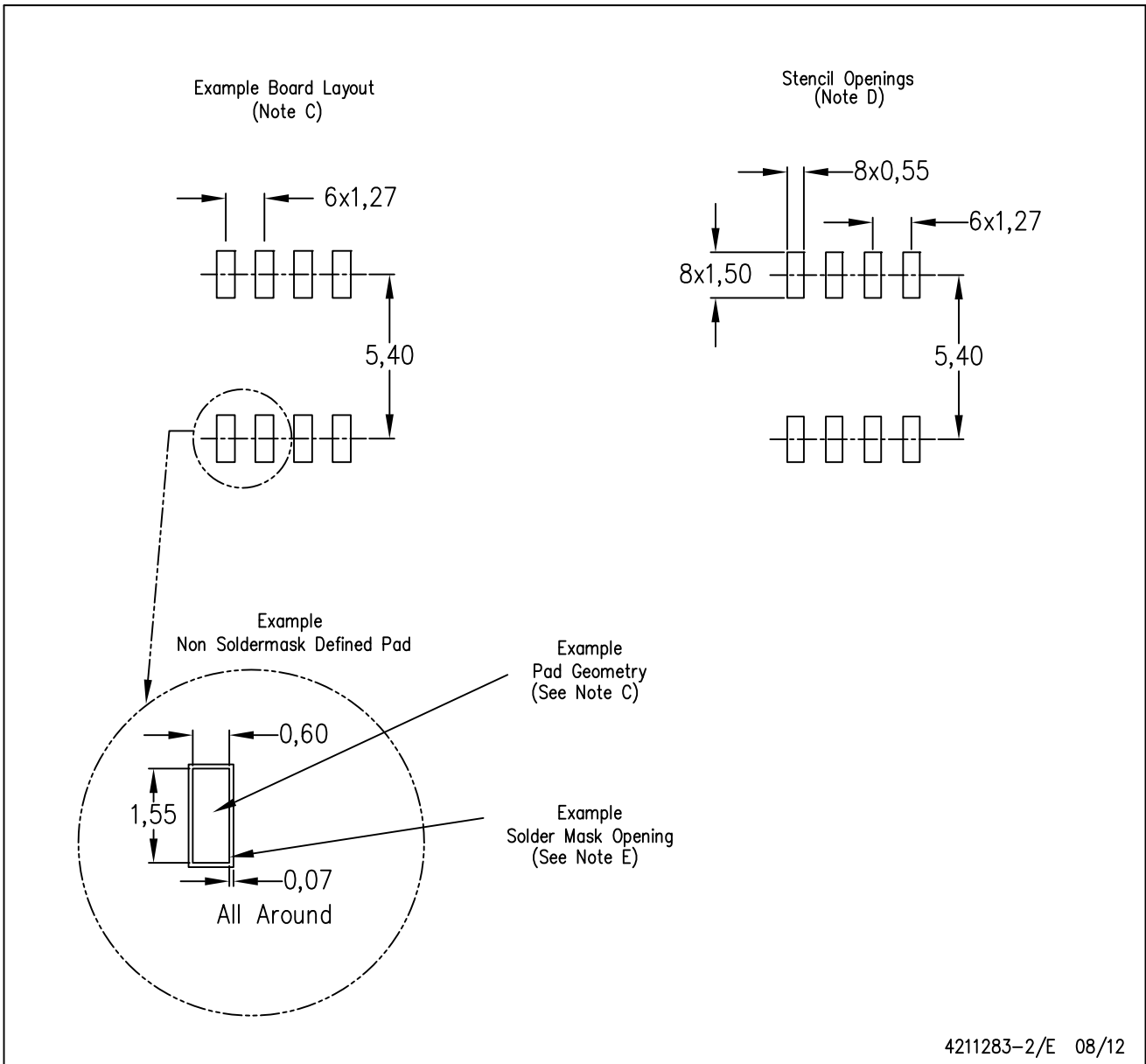
PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
 - D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
 - E. Reference JEDEC MS-012 variation AA.

D (R-PDSO-G8)

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.

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