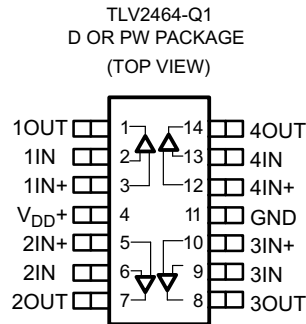
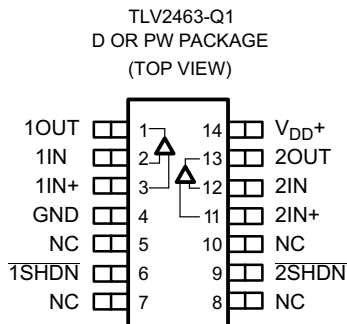
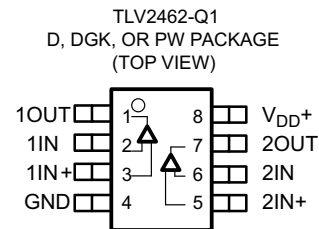
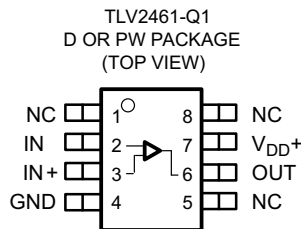
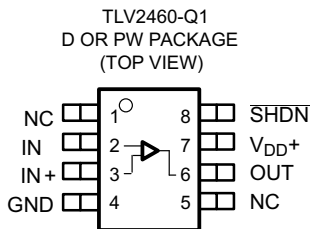


## LOW-POWER RAIL-TO-RAIL INPUT/OUTPUT OPERATIONAL AMPLIFIERS WITH SHUTDOWN

Check for Samples: [TLV2460-Q1](#), [TLV2461-Q1](#), [TLV2462-Q1](#), [TLV2463-Q1](#), [TLV2464-Q1](#), [TLV2460A-Q1](#), [TLV2461A-Q1](#), [TLV2462A-Q1](#), [TLV2463A-Q1](#), [TLV2464A-Q1](#)

### FEATURES

- 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)
- Rail-to-Rail Output Swing
- Gain Bandwidth Product . . . 6.4 MHz
- ±80-mA Output Drive Capability
- Supply Current . . . 500 µA/Channel
- Input Offset Voltage . . . 100 µV
- Input Noise Voltage . . . 11 nV/√Hz
- Slew Rate . . . 1.6 V/µs
- Micropower Shutdown Mode (TLV2460-Q1/TLV2463-Q1) . . . 0.3 µA/Channel
- Universal Operational Amplifier EVM



NC – No internal connection

### DESCRIPTION

The devices in the TLV246x-Q1 family of low-power rail-to-rail input/output operational amplifiers are specifically designed for portable applications. The input common-mode voltage range extends beyond the supply rails for maximum dynamic range in low-voltage systems. The amplifier output has rail-to-rail performance with high-output-drive capability, solving one of the limitations of older rail-to-rail input/output operational amplifiers. This rail-to-rail dynamic range and high output drive make the TLV246x-Q1 ideal for buffering analog-to-digital converters.

The operational amplifier has 6.4-MHz bandwidth and 1.6-V/µs slew rate with only 500-µA supply current, providing good ac performance with low power consumption. Devices are available with an optional shutdown terminal, which places the amplifier in an ultralow supply-current mode ( $I_{DD} = 0.3 \mu\text{A}/\text{channel}$ ). While in shutdown, the operational amplifier output is placed in a high-impedance state. DC applications are also well served with an input noise voltage of 11 nV/√Hz and input offset voltage of 100 µV.



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.

**ORDERING INFORMATION<sup>(1)</sup>**

T <sub>A</sub>	V <sub>IO</sub> max AT 25°C	ORDERABLE PART NUMBER <sup>(2)</sup>	TOP-SIDE MARKING
-40°C to 125°C	2000 μV	TLV2460QDRQ1	2460Q1
		TLV2461QDRQ1	2461Q1
		TLV2462QDRQ1	2462Q1
		TLV2463QDRQ1	2463Q1
		TLV2464QDRQ1 <sup>(3)</sup>	2464Q1
		TLV2460QPWRQ1	2460Q1
		TLV2461QPWRQ1	2461Q1
		TLV2462QPWRQ1	2462Q1
		TLV2463QPWRQ1	2463Q1
		TLV2464QPWRQ1 <sup>(3)</sup>	2464Q1
	TLV2462QDGRQ1	QVM	
	1500 μV	TLV2460AQDRQ1	2460AQ
		TLV2461AQDRQ1	2461AQ
		TLV2462AQDRQ1	2462AQ
		TLV2463AQDRQ1	TLV2463AQ1
		TLV2464AQDRQ1 <sup>(3)</sup>	2464AQ
		TLV2460AQPWRQ1	2460AQ
		TLV2461AQPWRQ1	2461AQ
		TLV2462AQPWRQ1	2462AQ
		TLV2463AQPWRQ1	2463AQ
TLV2464AQPWRQ1		2464AQ	

- (1) 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 [www.ti.com](http://www.ti.com).
- (2) Package drawings, thermal data, and symbolization are available at [www.ti.com/packaging](http://www.ti.com/packaging).
- (3) Product Preview

## ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>

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

$V_{DD}$	Supply voltage <sup>(2)</sup>		6 V
$V_{ID}$	Differential input voltage range		-0.2 V to $V_{DD} + 0.2$ V
$I_I$	Input current (any input)		±200 mA
$I_O$	Output current		±175 mA
$I_I$	Total input current (into $V_{DD+}$ )		175 mA
$I_O$	Total output current (out of GND)		175 mA
$T_A$	Operating free-air temperature range		-40°C to 125°C
$T_J$	Maximum junction temperature		150°C
$\theta_{JA}$	Thermal impedance, junction to ambient <sup>(3)</sup>	D (8 pin)	176°C/W
		D (14 pin)	123°C/W
		PW (8 pin)	259°C/W
		PW (14 pin)	174°C/W
		DGK (8 pin)	242°C/W
$T_{stg}$	Storage temperature range		-65°C to 150°C
	Latch-Up performance meets 100 mA per AEC-Q100 (Class I)		Class I
	Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds		260°C

(1) 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.

(2) All voltage values, except differential voltages, are with respect to GND.

(3) Package thermal impedance is calculated in accordance with JESD 51-5.

## RECOMMENDED OPERATING CONDITIONS

		MIN	MAX	UNIT	
$V_{DD}$	Supply voltage	Single supply	2.7	6	V
		Split supply	±1.35	±3	
$V_{ICR}$	Common-mode input voltage range	-0.2	$V_{DD} + 0.2$	V	
$T_A$	Operating free-air temperature	-40	125	°C	
	Shutdown on/off voltage level <sup>(1)</sup>	$V_{IH}$	2	V	
		$V_{IL}$			0.7

(1) Relative to voltage on the GND terminal of the device

## ELECTRICAL CHARACTERISTICS

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

PARAMETER	TEST CONDITIONS	$T_A$ (1)	MIN	TYP	MAX	UNIT
$V_{IO}$ Input offset voltage	$V_{DD} = 3\text{ V}$ , $V_{IC} = 1.5\text{ V}$ , $V_O = 1.5\text{ V}$ , $R_S = 50\ \Omega$	TLV246x-Q1	25°C	100	2000	$\mu\text{V}$
			Full range		2200	
		TLV246xA-Q1	25°C	150	1500	
			Full range		1700	
$\alpha_{VIO}$ Temperature coefficient of input offset voltage	$V_{DD} = 3\text{ V}$ , $V_{IC} = 1.5\text{ V}$ , $V_O = 1.5\text{ V}$ , $R_S = 50\ \Omega$			2		$\mu\text{V}/^\circ\text{C}$
$I_{IO}$ Input offset current	$V_{DD} = 3\text{ V}$ , $V_{IC} = 1.5\text{ V}$ , $V_O = 1.5\text{ V}$ , $R_S = 50\ \Omega$	25°C		2.8	7	$\text{pA}$
		Full range			75	
$I_{IB}$ Input bias current	$V_{IC} = 1.5\text{ V}$ , $V_O = 1.5\text{ V}$ , $R_S = 50\ \Omega$	25°C		4.4	14	$\text{pA}$
		Full range			75	
$V_{OH}$ High-level output voltage	$I_O = -2.5\text{ mA}$	25°C		2.9		$\text{V}$
		Full range		2.8		
	$I_O = -10\text{ mA}$	25°C		2.7		
		Full range		2.5		
$V_{OL}$ Low-level output voltage	$V_{IC} = 1.5\text{ V}$ , $I_{OL} = 2.5\text{ mA}$	25°C		0.1		$\text{V}$
		Full range			0.2	
	$V_{IC} = 1.5\text{ V}$ , $I_{OL} = 10\text{ mA}$	25°C		0.3		
		Full range			0.5	
$I_{OS}$ Short circuit output current	Sourcing	25°C		50		$\text{mA}$
		Full range		20		
	Sinking	25°C		40		
		Full range		20		
$I_O$ Output current	Measured 1 V from rail	25°C		$\pm 40$		$\text{mA}$
$A_{VD}$ Large-signal differential voltage amplification	$R_L = 10\text{ k}\Omega$	25°C		90	105	$\text{dB}$
		Full range		89		
$r_{i(d)}$ Differential input resistance		25°C		$10^9$		$\Omega$
$C_{i(o)}$ Common-mode input capacitance	$f = 10\text{ kHz}$	25°C		7		$\text{pF}$
$z_o$ Closed-loop output impedance	$f = 100\text{ kHz}$ , $A_V = 10$	25°C		33		$\Omega$
CMRR Common-mode rejection ratio	$V_{ICR} = 0\text{ V to }3\text{ V}$ , $R_S = 50\ \Omega$	25°C		66	80	$\text{dB}$
		Full range		60		
$k_{SVR}$ Supply-voltage rejection ratio ( $\Delta V_{DD\pm}/\Delta V_{IO}$ )	$V_{DD} = 2.7\text{ V to }6\text{ V}$ , $V_{IC} = V_{DD}/2$ , No load	25°C		80	85	$\text{dB}$
		Full range		75		
	$V_{DD} = 3\text{ V to }5\text{ V}$ , $V_{IC} = V_{DD}/2$ , No load	25°C		85	95	
		Full range		80		
$I_{DD}$ Supply current (per channel)	$V_O = 1.5\text{ V}$ , No load	25°C		0.5	0.575	$\text{mA}$
		Full range			0.9	
$I_{DD(SHDN)}$ Supply current in shutdown (TLV2460-Q1, TLV2463-Q1)	$\overline{\text{SHDN}} < 0.7\text{ V}$ , Per channel in shutdown	25°C		0.3		$\mu\text{A}$
		Full range			2.5	

(1) Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ .

## OPERATING CHARACTERISTICS

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

PARAMETER		TEST CONDITIONS		$T_A$ <sup>(1)</sup>	MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	$V_{O(PP)} = 2\text{ V}$ , $C_L = 160\text{ pF}$ , $R_L = 10\text{ k}\Omega$		25°C	1	1.6		V/ $\mu\text{s}$
				Full range	0.8			
$V_n$	Equivalent input noise voltage	$f = 100\text{ Hz}$ $f = 1\text{ kHz}$		25°C	16			nV/ $\sqrt{\text{Hz}}$
					11			
$I_n$	Equivalent input noise current	$f = 1\text{ kHz}$		25°C	0.13		pA/ $\sqrt{\text{Hz}}$	
THD+N	Total harmonic distortion plus noise	$V_{O(PP)} = 2\text{ V}$ , $R_L = 10\text{ k}\Omega$ , $f = 1\text{ kHz}$		25°C	$A_V = 1$		0.006	%
					$A_V = 10$			
					$A_V = 100$			
$t_{(on)}$	Amplifier turn-on time	$A_V = 1$ , $R_L = 10\text{ k}\Omega$		25°C	Both channels		7.6	$\mu\text{s}$
					Channel 1 only, Channel 2 on		7.65	
$t_{(off)}$	Amplifier turn-off time	$A_V = 1$ , $R_L = 10\text{ k}\Omega$		25°C	Both channels		333	ns
					Channel 1 only, Channel 2 on		328	
					Channel 2 only, Channel 1 on		329	
Gain-bandwidth product		$f = 10\text{ kHz}$ , $C_L = 160\text{ pF}$ , $R_L = 10\text{ k}\Omega$		25°C	5.2		MHz	
$t_s$	Settling time	$V_{(STEP)PP} = 2\text{ V}$ , $A_V = -1$ , $C_L = 10\text{ pF}$ , $R_L = 10\text{ k}\Omega$		25°C	0.1%		1.47	$\mu\text{s}$
					0.01%		1.78	
					0.1%		1.77	
					0.01%		1.98	
$\Phi_m$	Phase margin at unity gain	$R_L = 10\text{ k}\Omega$ , $C_L = 160\text{ pF}$		25°C	44		°	
	Gain margin	$R_L = 10\text{ k}\Omega$ , $C_L = 160\text{ pF}$		25°C	7		dB	

 (1) Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ .

## ELECTRICAL CHARACTERISTICS

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

PARAMETER	TEST CONDITIONS		$T_A$ <sup>(1)</sup>	MIN	TYP	MAX	UNIT	
$V_{IO}$ Input offset voltage	$V_{DD} = 5\text{ V}$ , $V_{IC} = 2.5\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 50\ \Omega$	TLV246x-Q1	25°C		150	2000	$\mu\text{V}$	
			Full range			2200		
		TLV246xA-Q1	25°C		150	1500		
			Full range			1700		
$\alpha_{VIO}$ Temperature coefficient of input offset voltage	$V_{DD} = 5\text{ V}$ , $V_{IC} = 2.5\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 50\ \Omega$				2		$\mu\text{V}/^\circ\text{C}$	
$I_{IO}$ Input offset current	$V_{DD} = 5\text{ V}$ , $V_{IC} = 2.5\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 50\ \Omega$		25°C		0.3	7	$\text{pA}$	
			Full range			60		
$I_{IB}$ Input bias current	$V_{DD} = 5\text{ V}$ , $V_{IC} = 2.5\text{ V}$ , $V_O = 2.5\text{ V}$ , $R_S = 50\ \Omega$		25°C		1.3	14	$\text{pA}$	
			Full range			60		
$V_{OH}$ High-level output voltage	$I_O = -2.5\text{ mA}$		25°C		4.9		$\text{V}$	
			Full range		4.8			
		$I_O = -10\text{ mA}$	TLV246x-Q1, TLV246xA-Q1	25°C		4.8		
				Full range		4.7		
			TLV2462QDGKRQ1	25°C		4.8		
				Full range		4.4		
$V_{OL}$ Low-level output voltage	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 2.5\text{ mA}$		25°C		0.1		$\text{V}$	
			Full range			0.2		
	$V_{IC} = 2.5\text{ V}$ , $I_{OL} = 10\text{ mA}$		25°C		0.2			
			Full range			0.3		
$I_{OS}$ Short circuit output current	Sourcing		25°C		145		$\text{mA}$	
			Full range		60			
	Sinking		25°C		100			
			Full range		60			
$I_O$ Output current	Measured 1 V from rail		25°C		$\pm 80$		$\text{mA}$	
$A_{VD}$ Large-signal differential voltage amplification	$V_{IC} = 2.5\text{ V}$ , $R_L = 10\text{ k}\Omega$ , $V_O = 1\text{ V to }4\text{ V}$		25°C		92	109	$\text{dB}$	
			Full range		90			
$r_{i(d)}$ Differential input resistance			25°C		$10^9$		$\Omega$	
$C_{i(o)}$ Common-mode input capacitance	$f = 10\text{ kHz}$		25°C		7		$\text{pF}$	
$z_o$ Closed-loop output impedance	$f = 100\text{ kHz}$ , $A_V = 10$		25°C		29		$\Omega$	
CMRR Common-mode rejection ratio	$V_{ICR} = 0\text{ V to }5\text{ V}$ , $R_S = 50\ \Omega$		25°C		71	85	$\text{dB}$	
			Full range		60			
$k_{SVR}$ Supply-voltage rejection ratio ( $\Delta V_{DD\pm}/\Delta V_{IO}$ )	$V_{DD} = 2.7\text{ V to }6\text{ V}$ , $V_{IC} = V_{DD}/2$ , No load		25°C		80	85	$\text{dB}$	
			Full range		75			
	$V_{DD} = 3\text{ V to }5\text{ V}$ , $V_{IC} = V_{DD}/2$ , No load		25°C		85	95		
			Full range		80			
$I_{DD}$ Supply current (per channel)	$V_O = 2.5\text{ V}$ , No load		25°C		0.55	0.65	$\text{mA}$	
			Full range			1		
$I_{DD(SHDN)}$ Supply current in shutdown (TLV2460-Q1, TLV2463-Q1)	$\overline{\text{SHDN}} < 0.7\text{ V}$ , Per channel in shutdown		25°C		1		$\mu\text{A}$	
			Full range			3		

(1) Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ .

## OPERATING CHARACTERISTICS

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

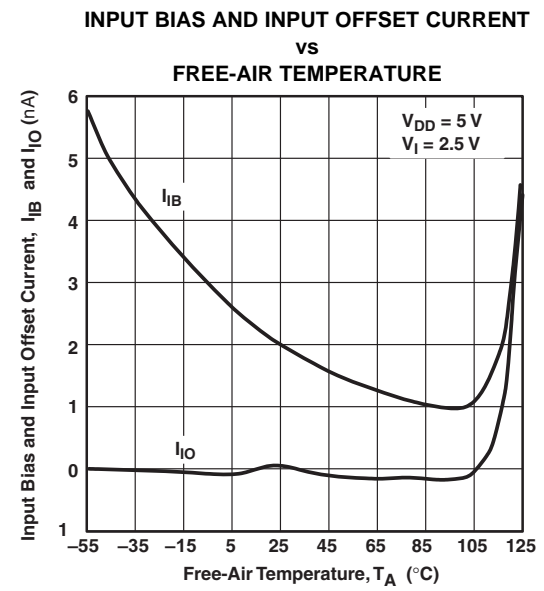
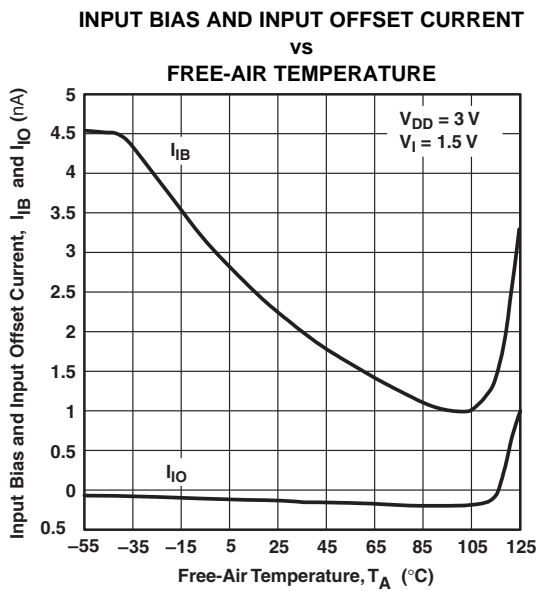
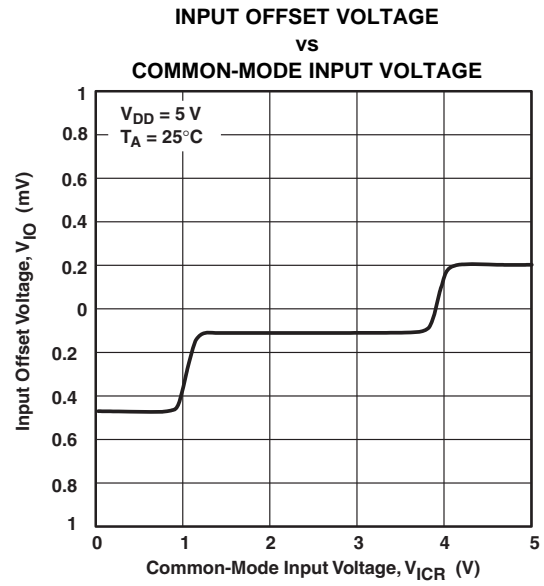
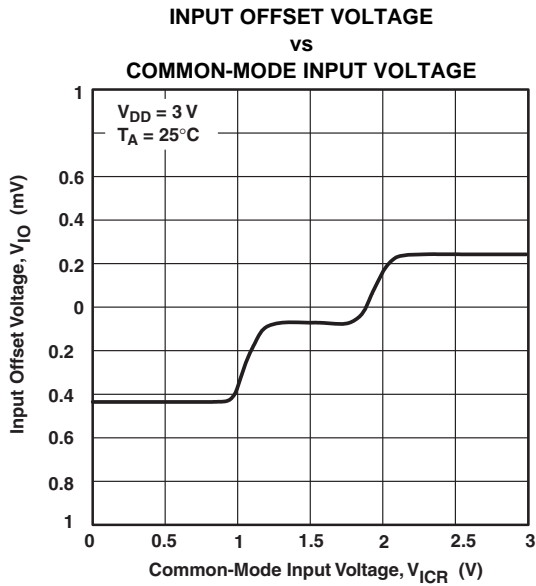
PARAMETER		TEST CONDITIONS		$T_A$ <sup>(1)</sup>	MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	$V_{O(PP)} = 2\text{ V}$ , $C_L = 160\text{ pF}$ , $R_L = 10\text{ k}\Omega$		25°C	1	1.6		V/ $\mu$ s
				Full range	0.8			
$V_n$	Equivalent input noise voltage	$f = 100\text{ Hz}$ $f = 1\text{ kHz}$		25°C	14			nV/ $\sqrt{\text{Hz}}$
					11			
$I_n$	Equivalent input noise current	$f = 100\text{ Hz}$		25°C	0.13		pA/ $\sqrt{\text{Hz}}$	
THD+N	Total harmonic distortion plus noise	$V_{O(PP)} = 4\text{ V}$ , $R_L = 10\text{ k}\Omega$ , $f = 10\text{ kHz}$		25°C	$A_V = 1$		0.004	%
					$A_V = 10$			
					$A_V = 100$			
$t_{(on)}$	Amplifier turn-on time	$A_V = 1$ , $R_L = 10\text{ k}\Omega$		25°C	Both channels		7.6	$\mu$ s
					Channel 1 only, Channel 2 on			
					Channel 2 only, Channel 1 on			
$t_{(off)}$	Amplifier turn-off time	$A_V = 1$ , $R_L = 10\text{ k}\Omega$		25°C	Both channels		333	ns
					Channel 1 only, Channel 2 on			
					Channel 2 only, Channel 1 on			
Gain-bandwidth product		$f = 10\text{ kHz}$ , $C_L = 160\text{ pF}$ , $R_L = 10\text{ k}\Omega$		25°C	6.4		MHz	
$t_s$	Settling time	$V_{(STEP)PP} = 2\text{ V}$ , $A_V = -1$ , $C_L = 10\text{ pF}$ , $R_L = 10\text{ k}\Omega$		25°C	0.1%		1.53	$\mu$ s
					0.01%			
					0.1%			
					0.01%			
$\Phi_m$	Phase margin at unity gain	$R_L = 10\text{ k}\Omega$ , $C_L = 160\text{ pF}$		25°C	45		°	
Gain margin		$R_L = 10\text{ k}\Omega$ , $C_L = 160\text{ pF}$		25°C	7		dB	

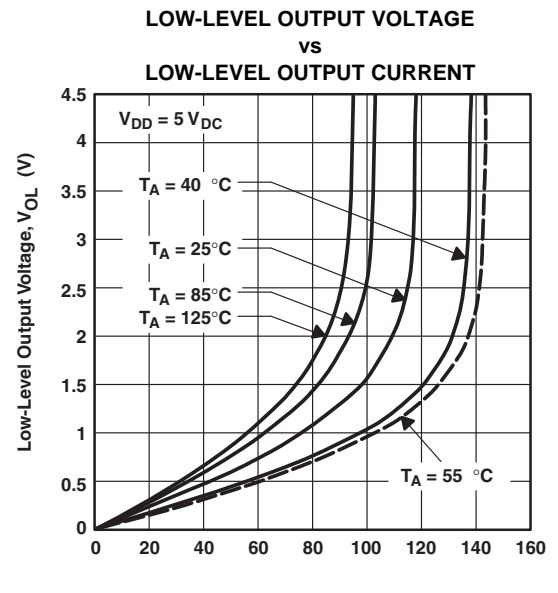
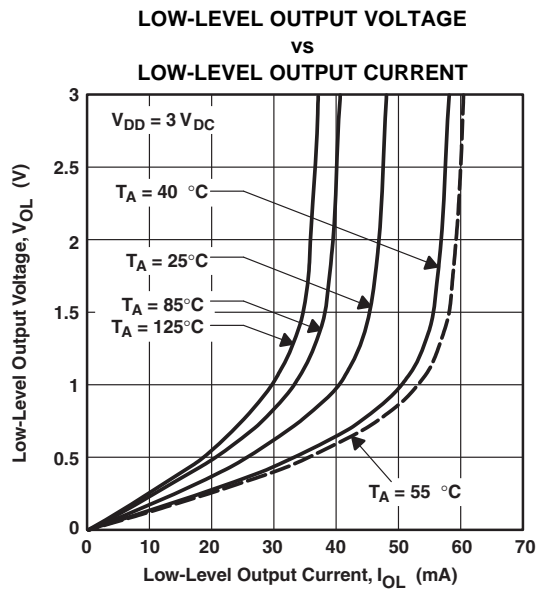
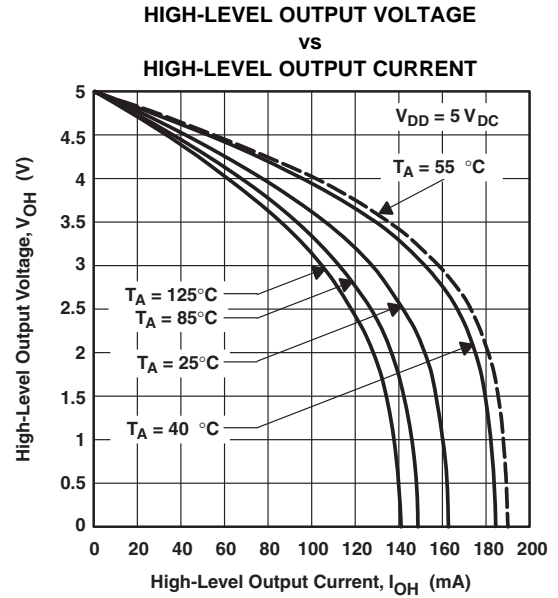
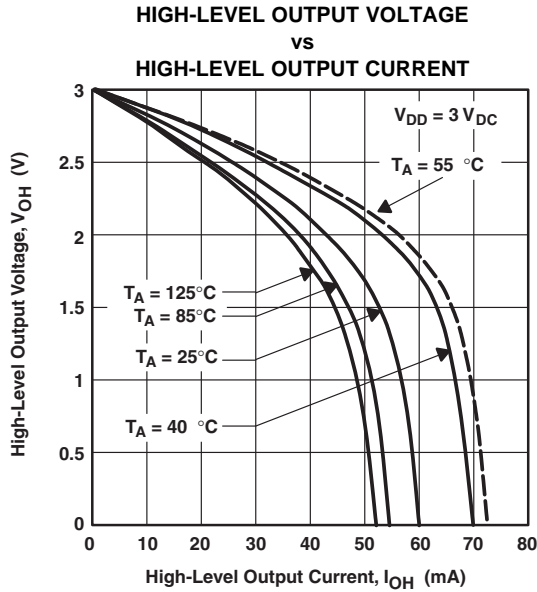
 (1) Full range is  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ .

## TYPICAL CHARACTERISTICS

### Table of Graphs

			FIGURE
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$I_{IO}$	Input offset current	vs Free-air temperature	3, 4
$V_{OH}$	High-level output voltage	vs High-level output current	5, 6
$V_{OL}$	Low-level output voltage	vs Low-level output current	7, 8
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	Supply current turnoff		25
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SR	Slew rate	vs Load capacitance	27
$V_n$	Equivalent input noise voltage	vs Frequency	28, 29
		vs Common-mode input voltage	30, 31
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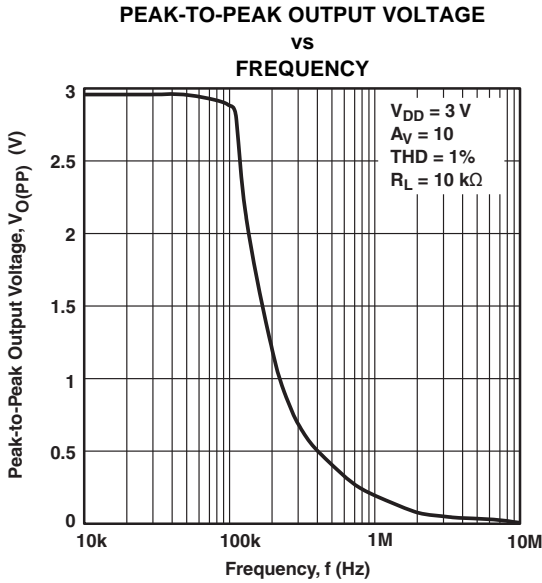


Figure 9.

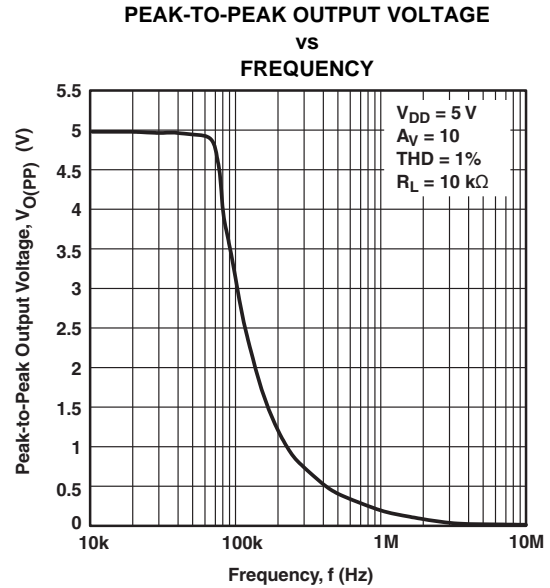


Figure 10.

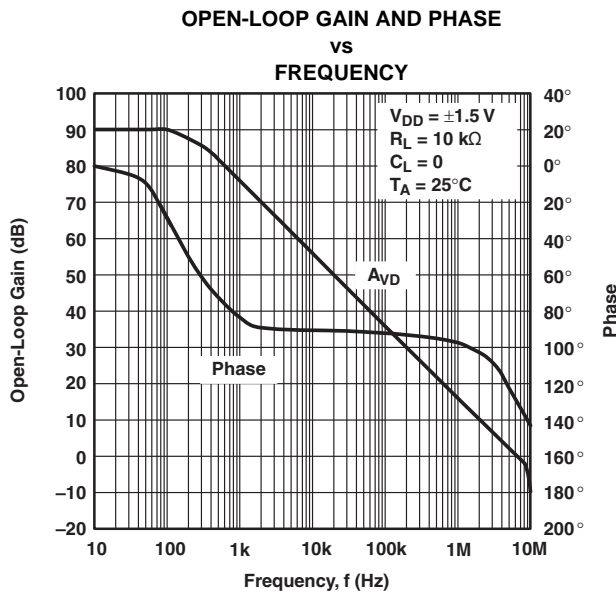


Figure 11.

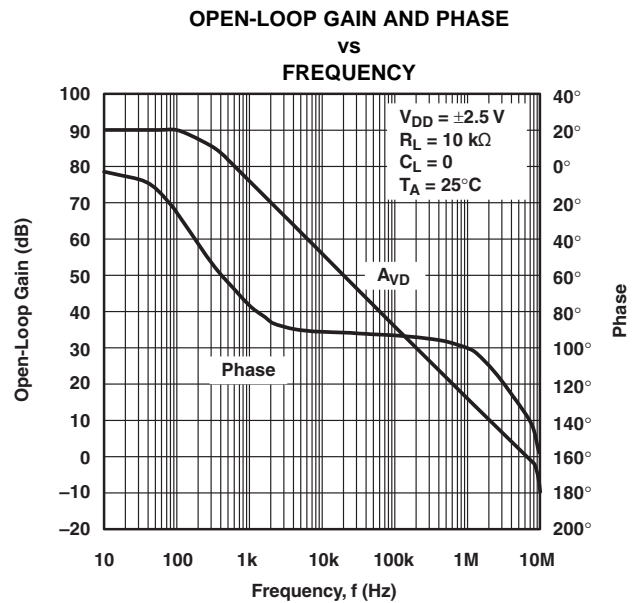


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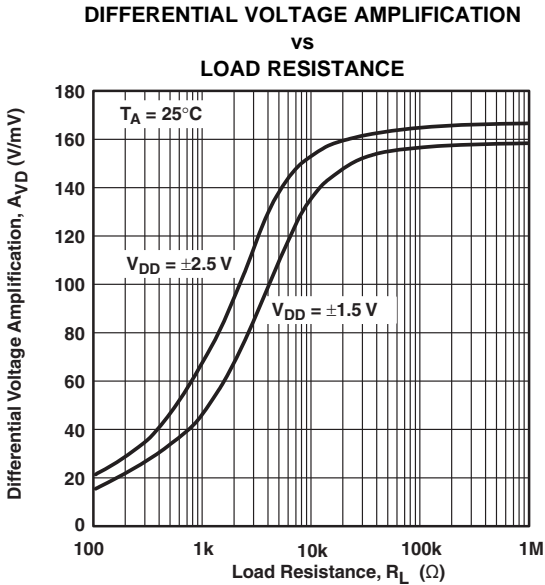


Figure 13.

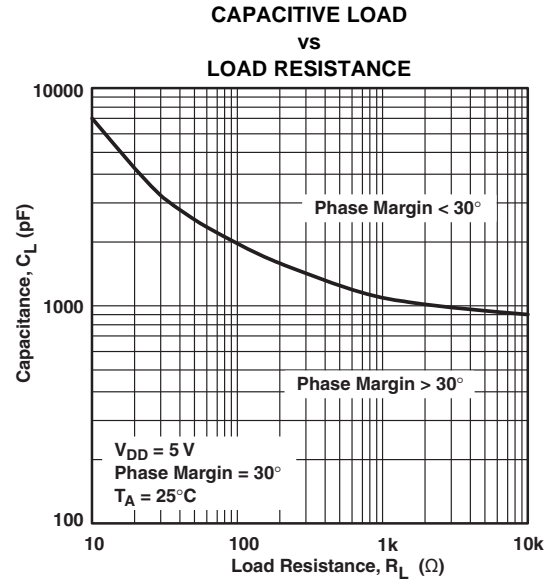


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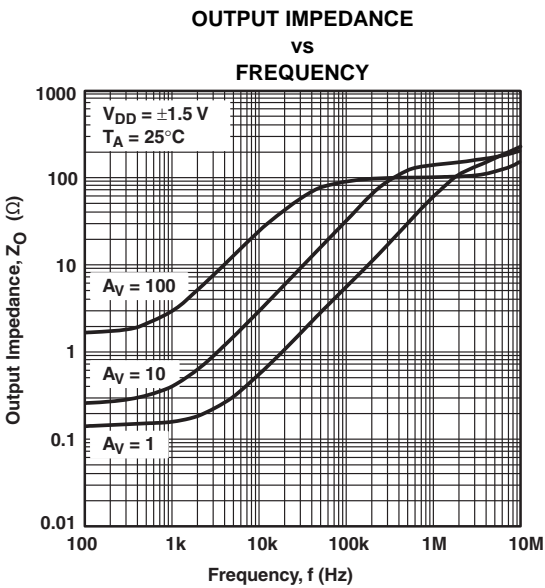


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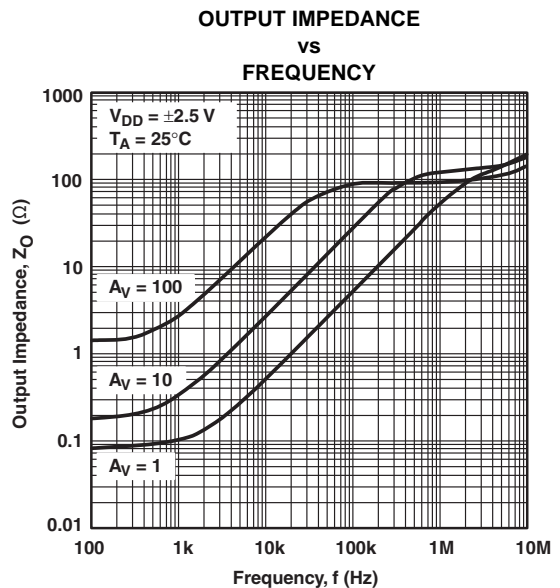
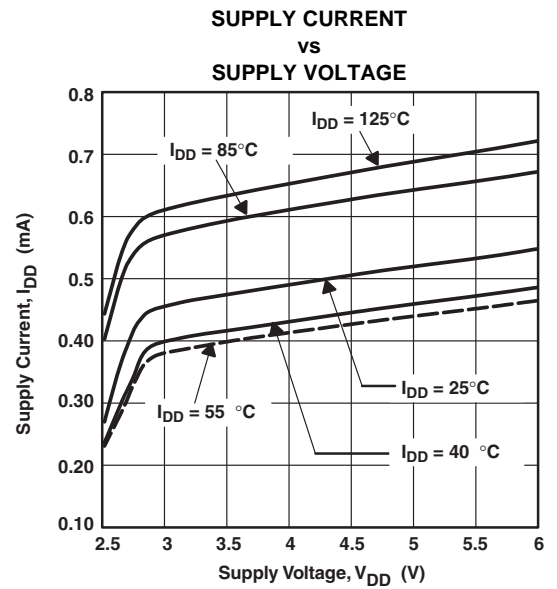
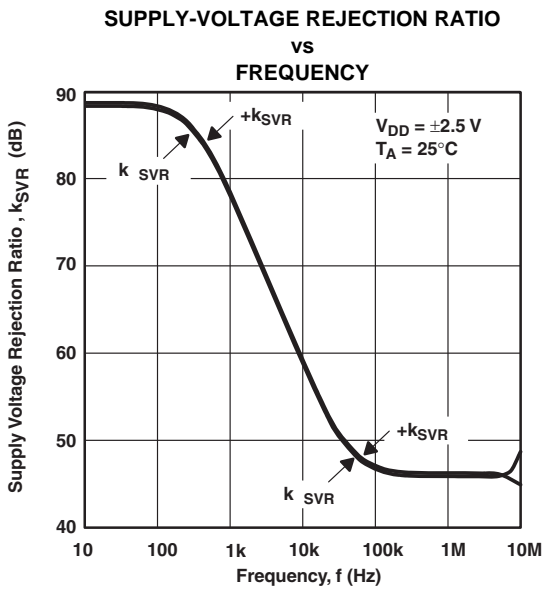
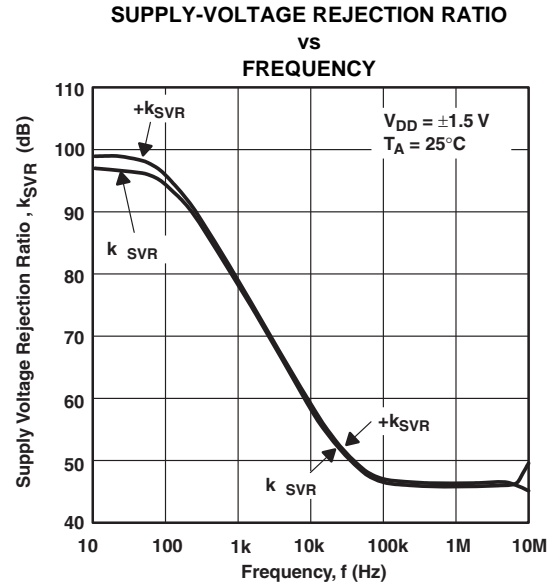
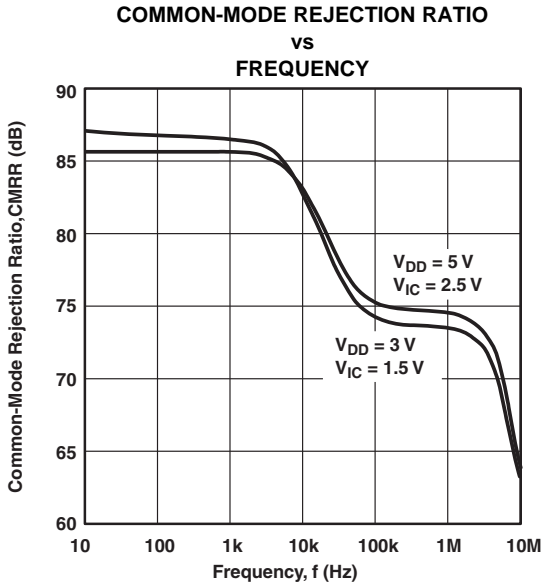


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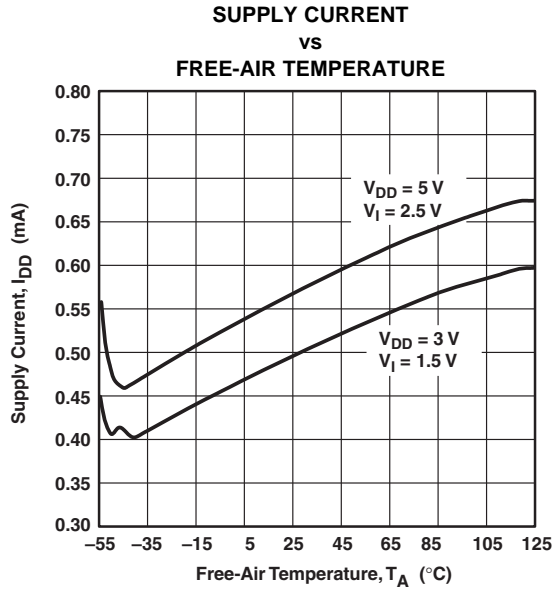


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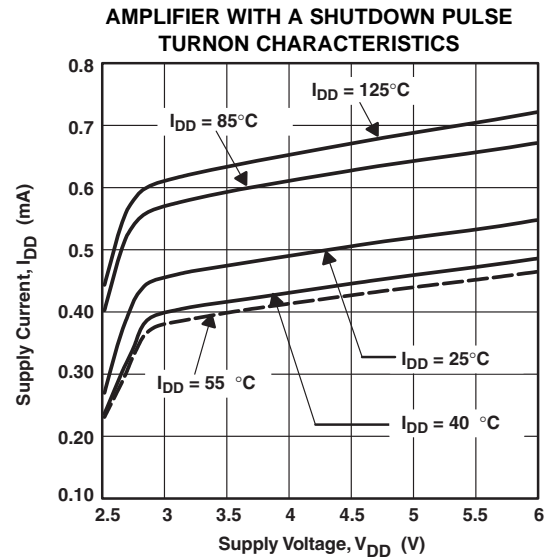


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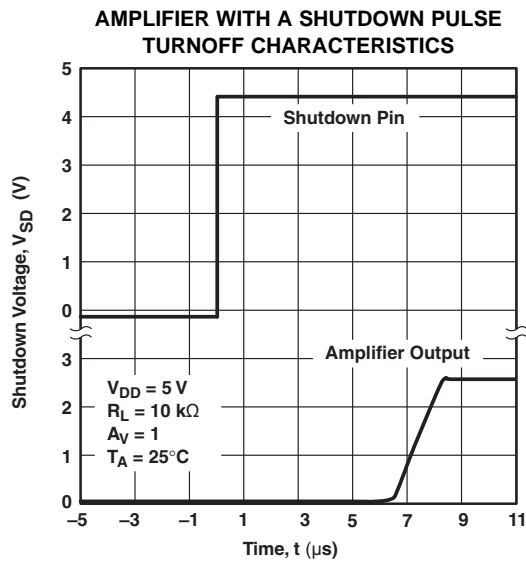


Figure 23.

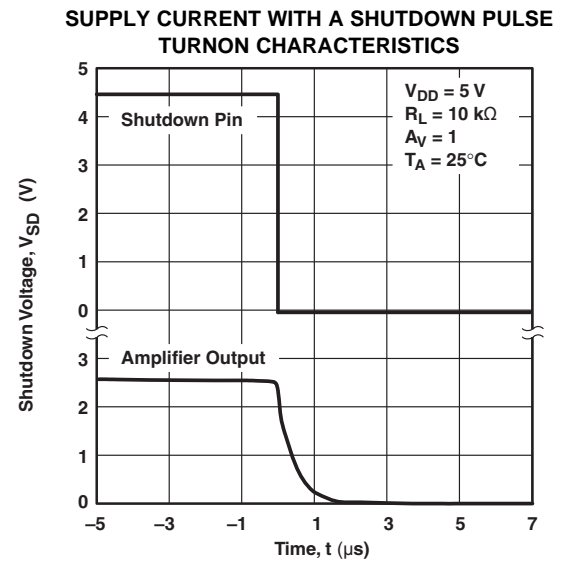
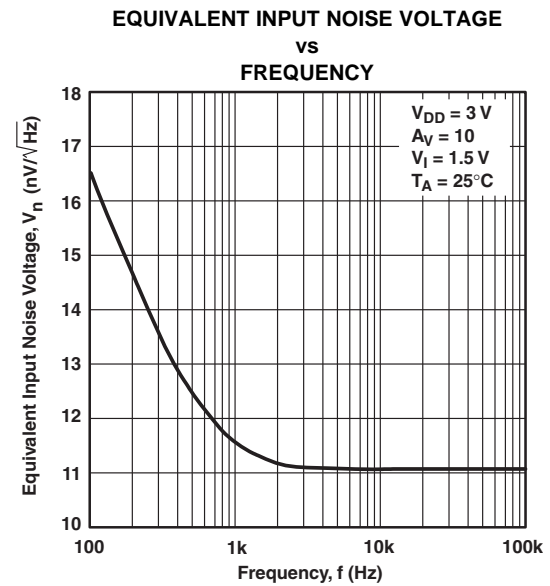
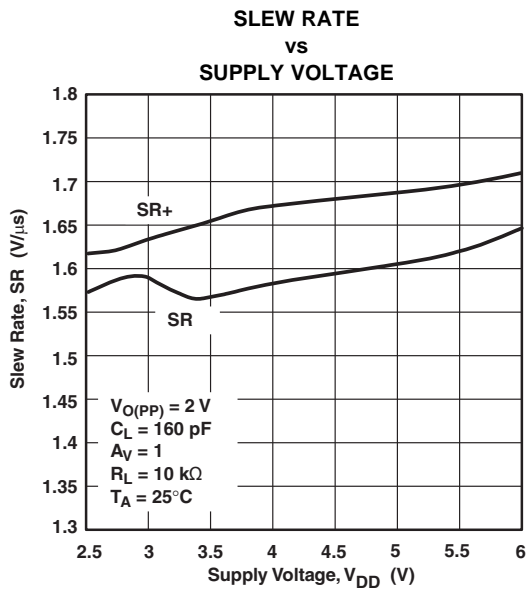
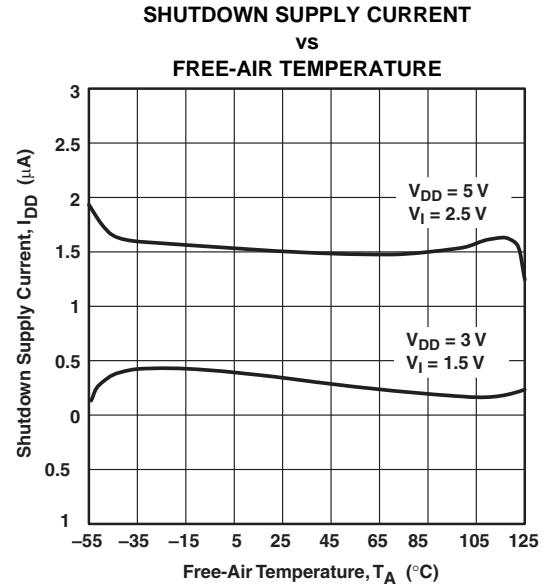
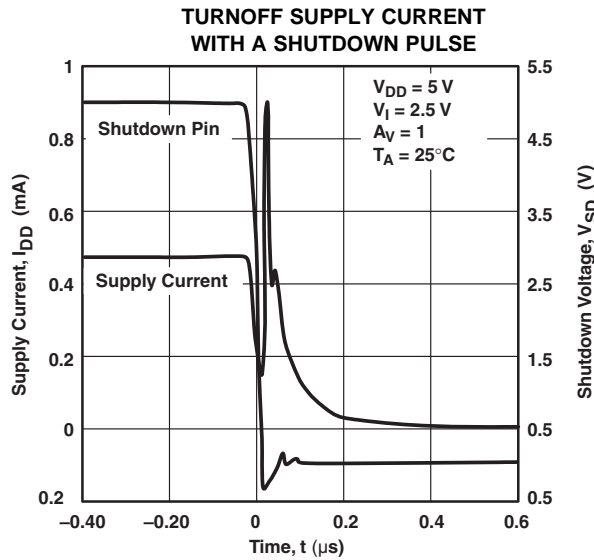


Figure 24.



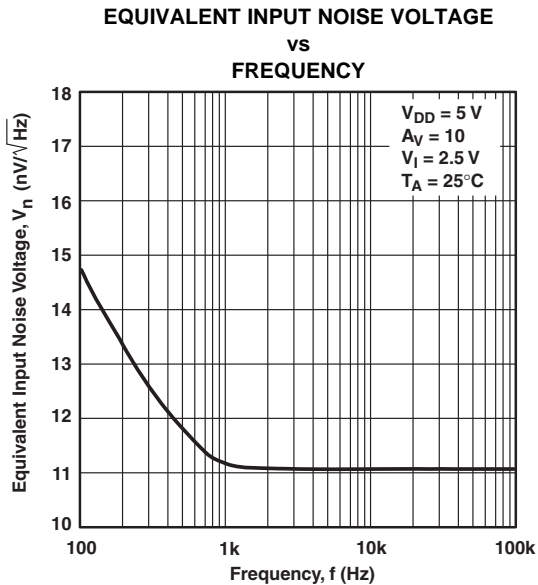


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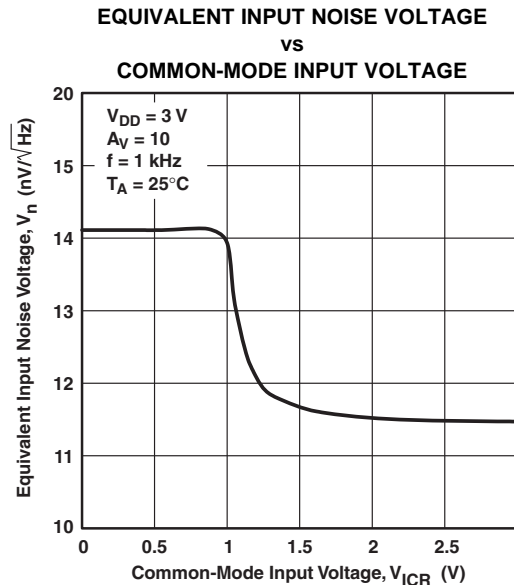


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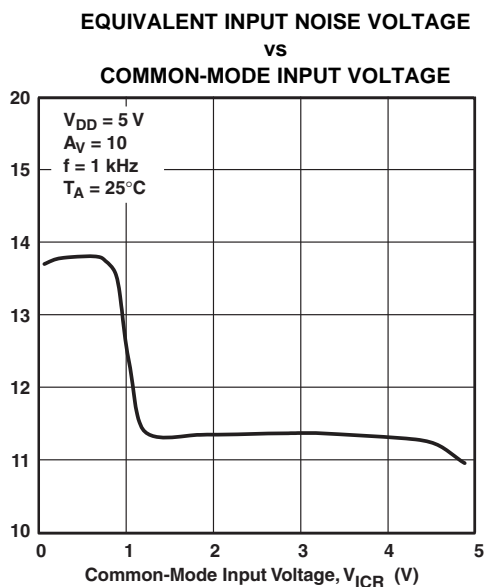


Figure 31.

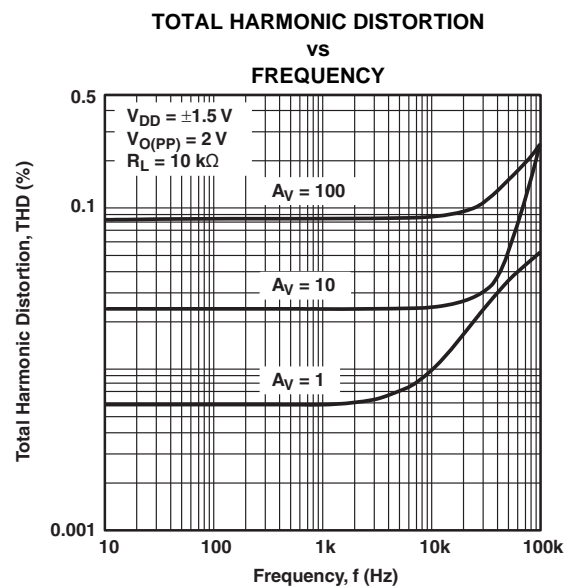


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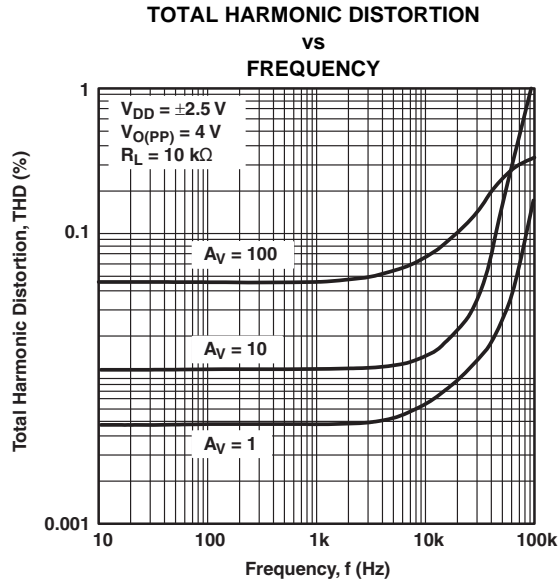


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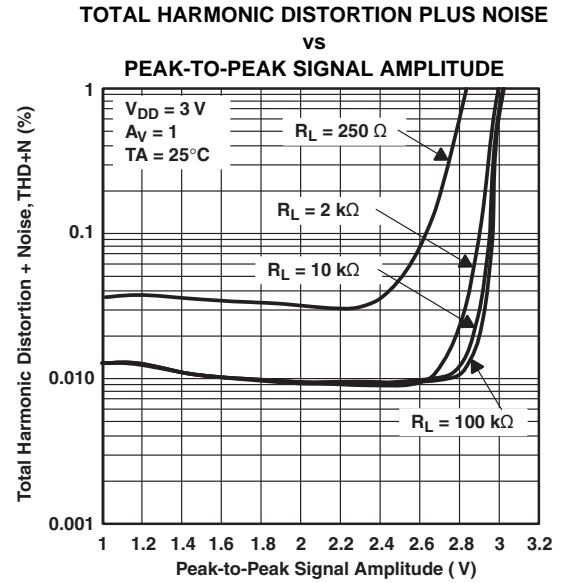


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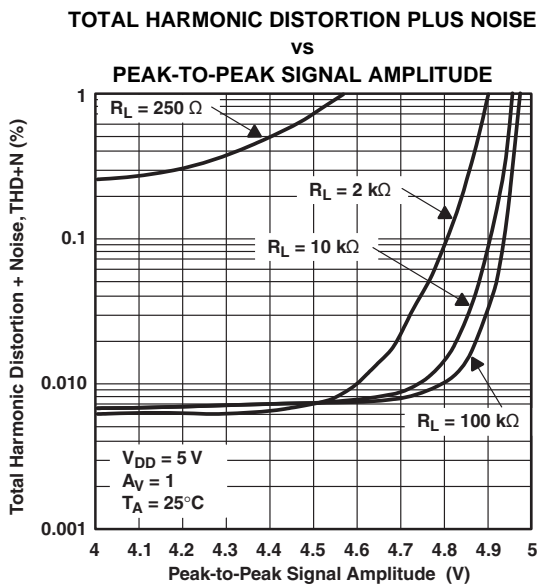


Figure 35.

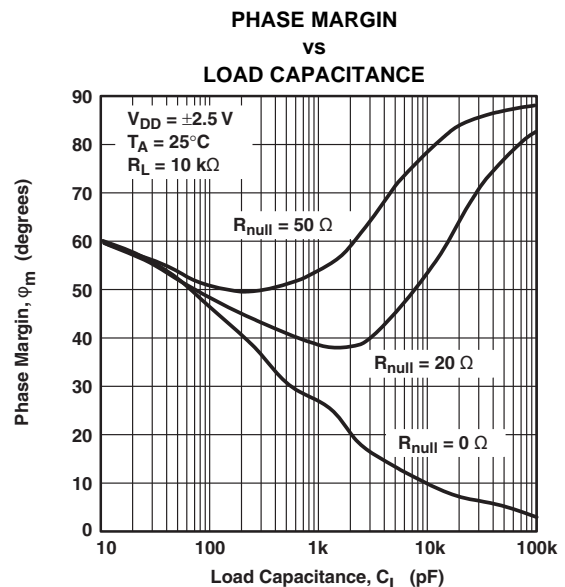


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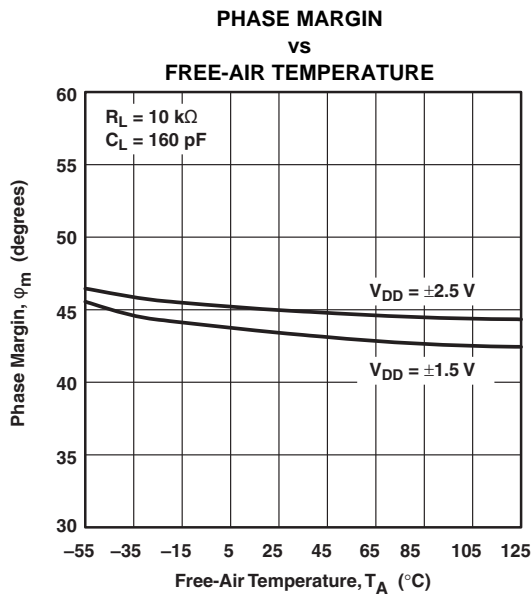


Figure 37.

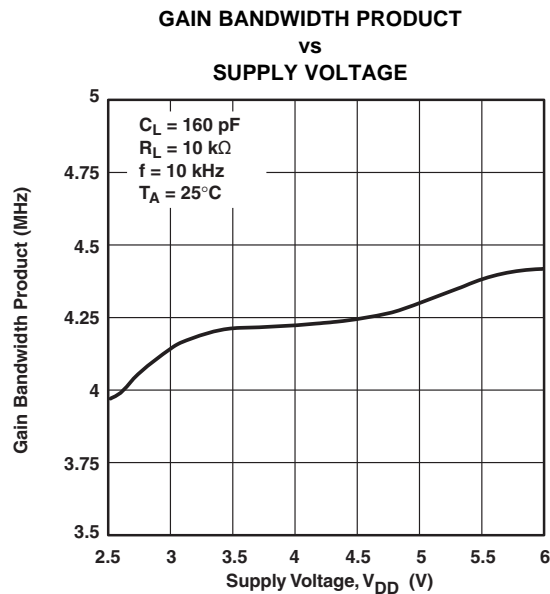


Figure 38.

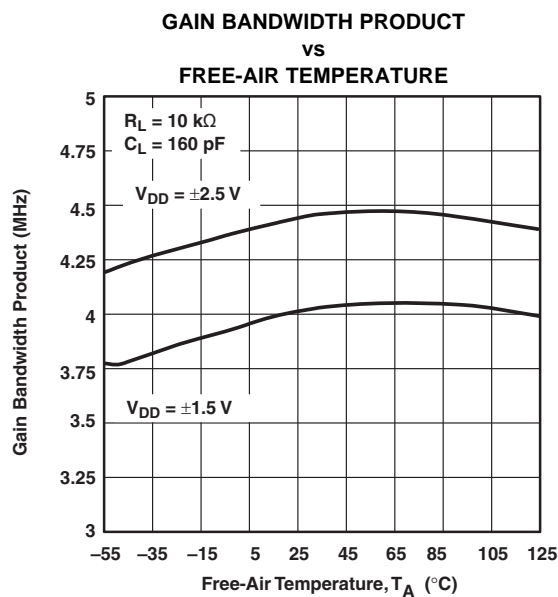


Figure 39.

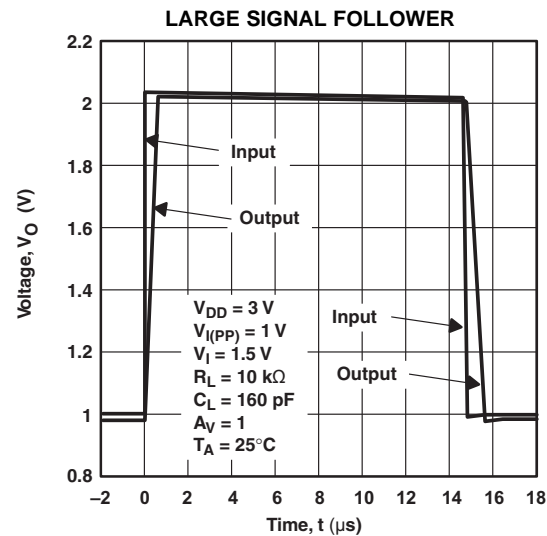


Figure 40.

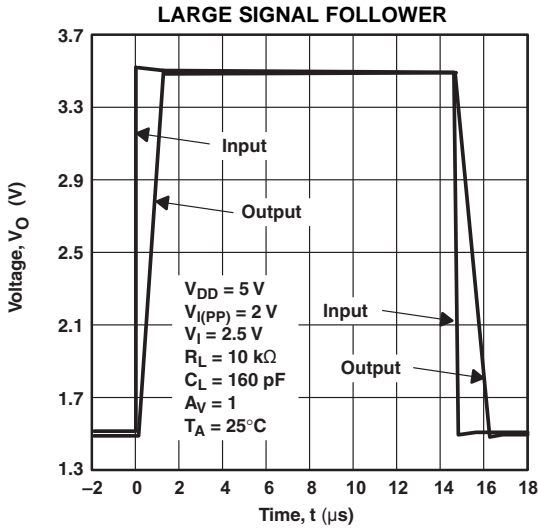


Figure 41.

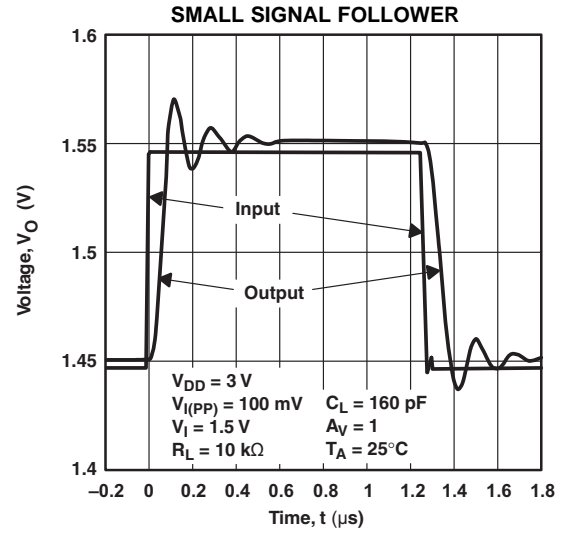


Figure 42.

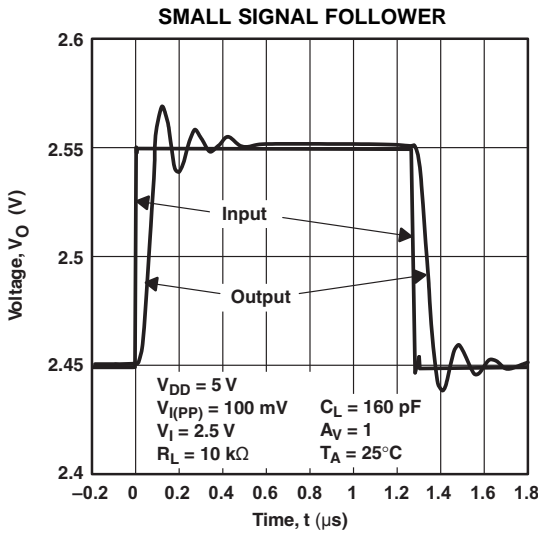


Figure 43.

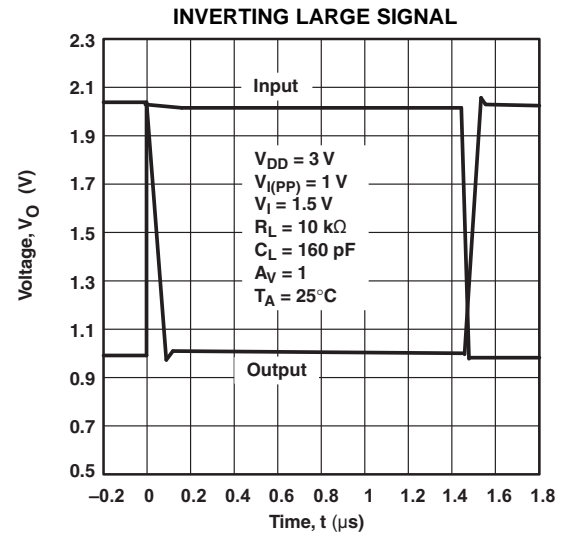


Figure 44.

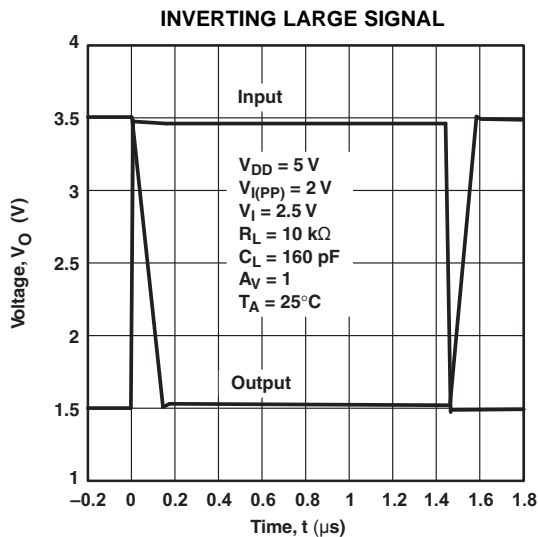


Figure 45.

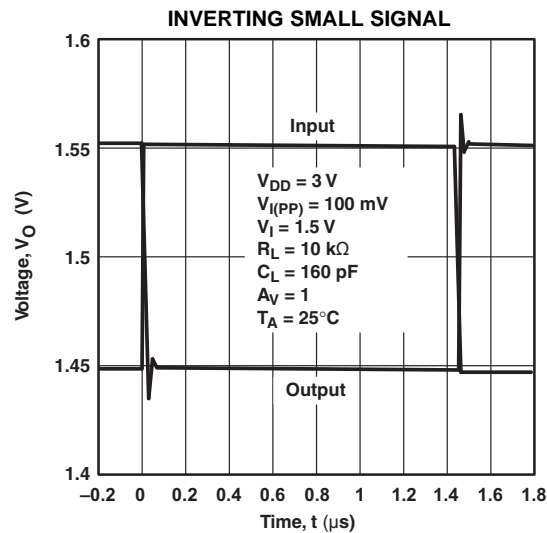


Figure 46.

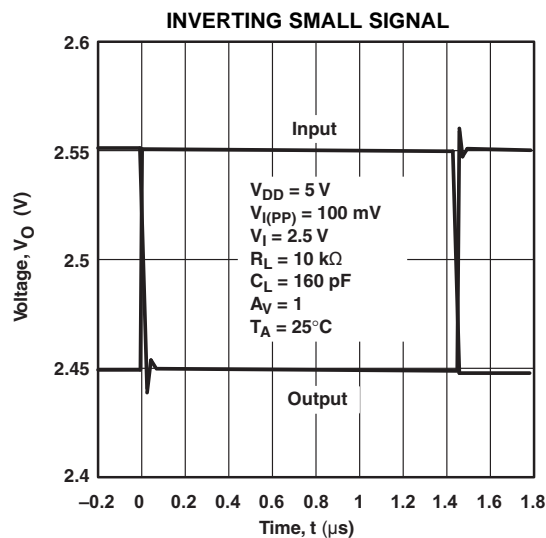


Figure 47.

### PARAMETER MEASUREMENT INFORMATION

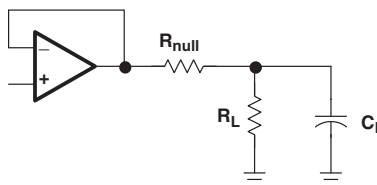
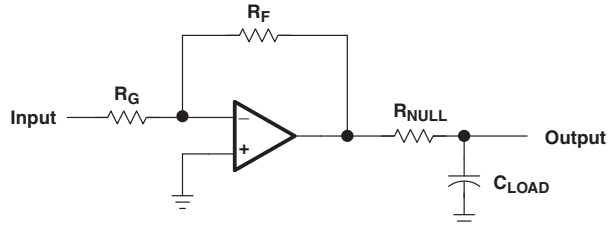


Figure 48.

## APPLICATION INFORMATION

### Driving a Capacitive Load

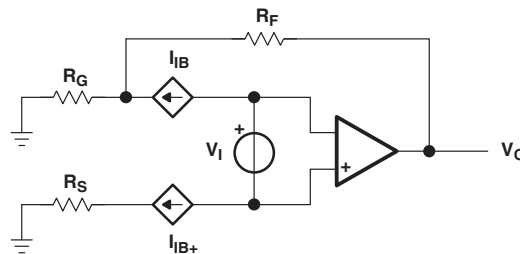
When the amplifier is configured in this manner, capacitive loading directly on the output decreases the phase margin of the device leading to high frequency ringing or oscillations. Therefore, for capacitive loads of greater than 10 pF, it is recommended that a resistor be placed in series ( $R_{NULL}$ ) with the output of the amplifier, as shown in [Figure 49](#). A minimum value of 20  $\Omega$  works well for most applications.



**Figure 49. Driving a Capacitive Load**

### Offset Voltage

The output offset voltage ( $V_{OO}$ ) is the sum of the input offset voltage ( $V_{IO}$ ) and both input bias currents ( $I_{IB}$ ) times the corresponding gains. The schematic and formula in [Figure 50](#) can be used to calculate the output offset voltage.

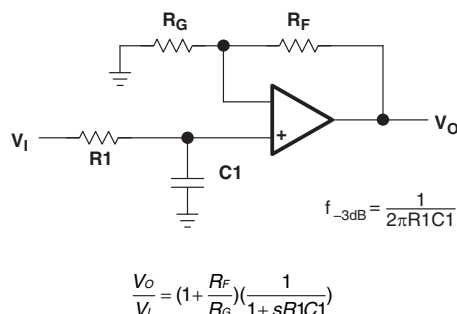


$$V_{OO} = V_{IO} \left( 1 + \left( \frac{R_F}{R_G} \right) \right) \pm I_{IB} + R_S \left( 1 + \left( \frac{R_F}{R_G} \right) \right) \pm I_{IB} - R_F$$

**Figure 50. Output Offset Voltage Model**

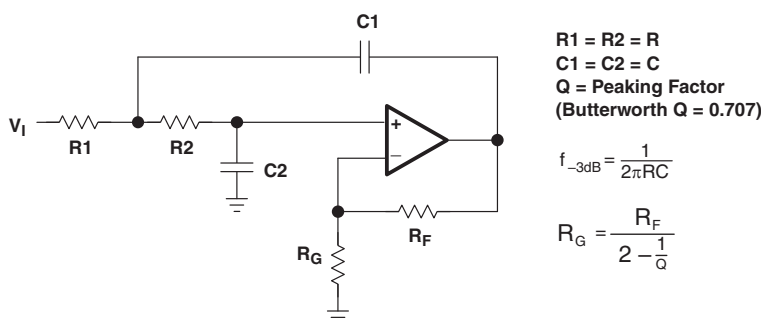
## General Configurations

When receiving low-level signals, limiting the bandwidth of the incoming signals into the system is often required. The simplest way to accomplish this is to place an RC filter at the noninverting terminal of the amplifier (see [Figure 51](#)).



**Figure 51. Single-Pole Low-Pass Filter**

If even more attenuation is needed, a multiple pole filter is required. The Sallen-Key filter can be used for this task. For best results, the amplifier should have a bandwidth that is eight to ten times the filter frequency bandwidth. Failure to do this can result in phase shift of the amplifier.



**Figure 52. 2-Pole Low-Pass Sallen-Key Filter**

## Shutdown Function

Two members of the TLV246x-Q1 family (TLV2460-Q1 and TLV2463-Q1) have a shutdown terminal for conserving battery life in portable applications. When the shutdown terminal is tied low, the supply current is reduced to 0.3  $\mu\text{A}/\text{channel}$ , the amplifier is disabled, and the outputs are placed in a high-impedance mode. To enable the amplifier, the shutdown terminal can either be left floating or pulled high. When the shutdown terminal is left floating, care should be taken to ensure that parasitic leakage current at the shutdown terminal does not inadvertently place the operational amplifier into shutdown. The shutdown terminal threshold is always referenced to  $V_{DD} / 2$ . Therefore, when operating the device with split supply voltages (for example,  $\pm 2.5\text{ V}$ ), the shutdown terminal must be pulled to  $V_{DD-}$  (not GND) to disable the operational amplifier.

The amplifier's output with a shutdown pulse is shown in [Figure 22](#), [Figure 23](#), [Figure 24](#), and [Figure 25](#). The amplifier is powered with a single 5-V supply and configured as a noninverting configuration with a gain of 5. The amplifier turnon and turnoff times are measured from the 50% point of the shutdown pulse to the 50% point of the output waveform. The times for the single, dual, and quad are listed in the data tables.

## Circuit Layout Considerations

To achieve the levels of high performance of the TLV246x-Q1, follow proper printed-circuit board design techniques. A general set of guidelines is given in the following.

- Ground planes – It is highly recommended that a ground plane be used on the board to provide all components with a low inductive ground connection. However, in the areas of the amplifier inputs and output, the ground plane can be removed to minimize the stray capacitance.

- Proper power supply decoupling – Use a 6.8- $\mu\text{F}$  tantalum capacitor in parallel with a 0.1- $\mu\text{F}$  ceramic capacitor on each supply terminal. It may be possible to share the tantalum among several amplifiers depending on the application, but a 0.1- $\mu\text{F}$  ceramic capacitor should always be used on the supply terminal of every amplifier. In addition, the 0.1- $\mu\text{F}$  capacitor should be placed as close as possible to the supply terminal. As this distance increases, the inductance in the connecting trace makes the capacitor less effective. The designer should strive for distances of less than 0.1 inches between the device power terminals and the ceramic capacitors.
- Sockets – Sockets can be used but are not recommended. The additional lead inductance in the socket pins often leads to stability problems. Surface-mount packages soldered directly to the printed circuit board is the best implementation.
- Short trace runs/compact part placements – Optimum high performance is achieved when stray series inductance has been minimized. To realize this, the circuit layout should be made as compact as possible, thereby minimizing the length of all trace runs. Particular attention should be paid to the inverting input of the amplifier. Its length should be kept as short as possible. This minimizes stray capacitance at the input of the amplifier.
- Surface-mount passive components – Using surface-mount passive components is recommended for high-performance amplifier circuits for several reasons. First, because of the extremely low lead inductance of surface-mount components, the problem with stray series inductance is greatly reduced. Second, the small size of surface-mount components naturally leads to a more compact layout, thereby minimizing both stray inductance and capacitance. If leaded components are used, it is recommended that the lead lengths be kept as short as possible.

### General Power Dissipation Considerations

For a given  $\theta_{JA}$ , the maximum power dissipation is shown in [Figure 53](#) and is calculated by [Equation 1](#):

$$P_D = \left( \frac{T_{MAX} - T_A}{\theta_{JA}} \right) \quad (1)$$

Where:

$P_D$  = Maximum power dissipation of TLV246x-Q1 (watts)

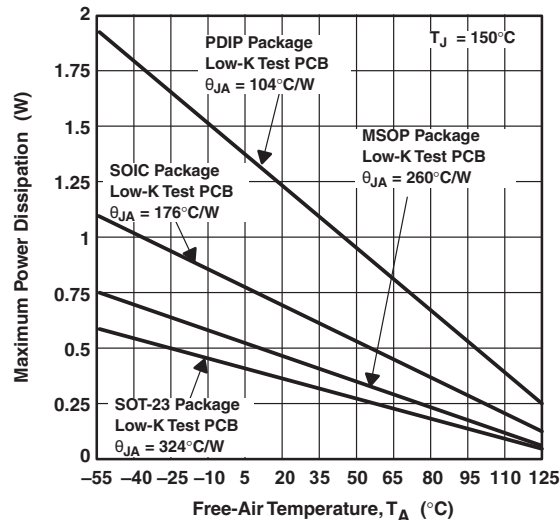
$T_{MAX}$  = Absolute maximum junction temperature (150°C)

$T_A$  = Ambient free-air temperature (°C)

$\theta_{JA} = \theta_{JC} + \theta_{CA}$

$\theta_{JC}$  = Thermal coefficient from junction to case

$\theta_{CA}$  = Thermal coefficient from case to ambient air (°C/W)



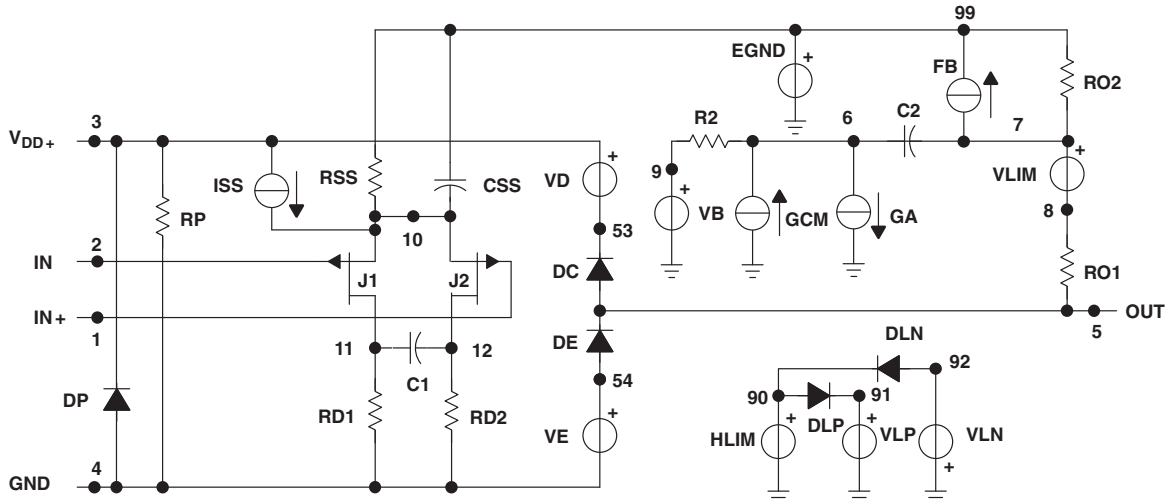
**Figure 53. Maximum Power Dissipation vs Free-Air Temperature**

## Macromodel Information

Macromodel information provided was derived using Microsim Parts™ Release 8, the model generation software used with Microsim PSpice™. The Boyle macromodel <sup>(1)</sup> and subcircuit in [Figure 54](#) were generated using the TLV246x-Q1 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):

(1) 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).

- 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



```
.SUBCKT TLV246X 1 2 3 4 5
C1 11 12 2.46034E-12
C2 6 7 10.0000E-12
CSS 10 99 443.21E-15
DC 5 53 DY
DE 54 5 DY
DLP 90 91 DX
DLN 92 90 DX
DP 4 3 DX
EGND 99 0 POLY (2) (3,0) (4,0) 0 .5 .5
FB 7 99 POLY (5) VB VC VE VLP
+ VLN 0 21.600E6 - 1E3 1E3 22E6 - 22E6
GA 6 0 11 12 345.26E- 6
GCM 0 6 10 99 15.4226E- 9
ISS 10 4 DC 18.850E- 6
HLIM 90 0 VLIM 1K
J1 11 2 10 JX1
J2 12 1 10 JX2
R2 6 9 100.00E3
```

```
RD1 3 11 2.8964E3
RD2 3 12 2.8964E3
RO1 8 5 5.6000
RO2 7 99 6.2000
RP 3 4 8.9127
RSS 10 99 10.610E6
VB 9 0 DC 0
VC 3 53 DC .7836
VE 54 4 DC .7436
VLIM 7 8 DC 0
VLP 91 0 DC 117
VLN 0 92 DC 117
.MODEL DX D (IS=800.00E-18)
.MODEL DY D (IS=800.00E-18 Rs = 1m Cjo=10p)
.MODEL JX1 NJF (IS=1.0000E-12 BETA=6.3239E-3
+ VTO=-1)
.MODEL JX2 NJF (IS=1.0000E-12 BETA=6.3239E-3
+ VTO=-1)
.ENDS
```

```
.subckt TLV_246Y 1 2 3 4 5 6
c1 11 12 2.4603E-12
c2 72 7 10.000E-12
css 10 99 443.21E-15
dc 70 53 dy
de 54 70 dy
dip 90 91 dx
din 92 90 dx
dp 4 3 dx
egnd 99 0 poly(2) (3,0) (4,0) 0 .5 .5
fb 7 99 poly(5) vb vc ve vlp vln 0
21.600E6 - 1E3 1E3 22E6 - 22E6
ga 72 0 11 12 345.26E- 6
gcm 0 72 10 99 15.422E- 9
iss 74 4 dc 18.850E- 6
hlim 90 0 vlim 1K
j1 11 2 10 jx1
j2 12 1 10 jx2
r2 72 9 100.00E3
rd1 3 11 2.8964E3
rd2 3 12 2.8964E3
ro1 8 70 5.6000
ro2 7 99 6.2000
```

```
rp 3 71 8.9127
rss 10 99 10.610E6
rs1 6 4 1G
rs2 6 4 1G
rs3 6 4 1G
rs4 6 4 1G
s1 71 4 6 4 s1x
s2 70 5 6 4 s1x
s3 10 74 6 4 s1x
s4 74 4 6 4 s2x
vb 9 0 dc 0
vc 3 53 dc .7836
ve 54 4 dc .7436
vlim 7 8 dc 0
vlp 91 0 dc 117
vln 0 92 dc 117
.model dx D(Is=800.00E-18)
.model dy D(Is=800.00E-18 Rs=1m Cjo=10p)
.model jx1 NJF(Is=1.0000E-12 Beta=6.3239E-3 Vto=-1)
.model jx2 NJF(Is=1.0000E-12 Beta=6.3239E-3 Vto=-1)
.model s1x VSWITCH(Roff=1E8 Ron=1.0 Voff=2.5 Von=0.0)
.model s2x VSWITCH(Roff=1E8 Ron=1.0 Voff=0 Von=2.5)
.ends
```

Figure 54. Boyle Macromodel and Subcircuit

## REVISION HISTORY

Changes from Revision D (September, 2010) to Revision E	Page
• Changed device names from TLV246xx to TLV246xx-Q1 throughout document. ....	1
• Removed package column from ordering information table. ....	2
• Changed $I_{DD}$ unit from $\mu A$ to mA. ....	4
• Changed $I_{DD}$ unit from $\mu A$ to mA ....	6

**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLV2460AQDRQ1	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI	-40 to 125	2460AQ	
TLV2460AQPWRG4Q1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2460AQ	<a href="#">Samples</a>
TLV2460AQPWRQ1	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	-40 to 125		
TLV2460QDRQ1	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI	-40 to 125		
TLV2460QPWRG4Q1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2460Q1	<a href="#">Samples</a>
TLV2460QPWRQ1	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	-40 to 125		
TLV2461AQDRQ1	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI	-40 to 125		
TLV2461AQPWRG4Q1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2461AQ	<a href="#">Samples</a>
TLV2461AQPWRQ1	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	-40 to 125		
TLV2461QDRQ1	OBSOLETE	SOIC	D	8		TBD	Call TI	Call TI	-40 to 125	2461Q1	
TLV2461QPWRG4Q1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2461Q1	<a href="#">Samples</a>
TLV2461QPWRQ1	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	-40 to 125		
TLV2462AQDRG4Q1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2462AQ	<a href="#">Samples</a>
TLV2462AQDRQ1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2462AQ	<a href="#">Samples</a>
TLV2462AQPWRG4Q1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2462AQ	<a href="#">Samples</a>
TLV2462AQPWRQ1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2462AQ	<a href="#">Samples</a>
TLV2462QDGKRQ1	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU   CU NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	QVM	<a href="#">Samples</a>
TLV2462QDRG4Q1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2462Q1	<a href="#">Samples</a>
TLV2462QDRQ1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2462Q1	<a href="#">Samples</a>
TLV2462QPWRG4Q1	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2462Q1	<a href="#">Samples</a>
TLV2462QPWRQ1	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	-40 to 125		

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLV2463AQDRQ1	OBSOLETE	SOIC	D	14		TBD	Call TI	Call TI	-40 to 125		
TLV2463AQPWRG4Q1	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2463AQ1	<b>Samples</b>
TLV2463AQPWRQ1	OBSOLETE	TSSOP	PW	14		TBD	Call TI	Call TI	-40 to 125		
TLV2463QDRQ1	OBSOLETE	SOIC	D	14		TBD	Call TI	Call TI	-40 to 125		
TLV2463QPWRG4Q1	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	2463Q1	<b>Samples</b>
TLV2463QPWRQ1	OBSOLETE	TSSOP	PW	14		TBD	Call TI	Call TI	-40 to 125	2463Q1	
TLV2464AQPWRG4Q1	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	V2464AQ	<b>Samples</b>
TLV2464AQPWRQ1	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	V2464AQ	<b>Samples</b>

(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.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

<sup>(6)</sup> Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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**OTHER QUALIFIED VERSIONS OF TLV2460-Q1, TLV2460A-Q1, TLV2461-Q1, TLV2461A-Q1, TLV2462-Q1, TLV2462A-Q1, TLV2463-Q1, TLV2463A-Q1, TLV2464A-Q1 :**

- Catalog: [TLV2460](#), [TLV2460A](#), [TLV2461](#), [TLV2461A](#), [TLV2462](#), [TLV2462A](#), [TLV2463](#), [TLV2463A](#), [TLV2464A](#)
- Enhanced Product: [TLV2462A-EP](#), [TLV2464A-EP](#)
- Military: [TLV2460M](#), [TLV2460AM](#), [TLV2461M](#), [TLV2461AM](#), [TLV2462M](#), [TLV2462AM](#), [TLV2463M](#), [TLV2463AM](#)

NOTE: Qualified Version Definitions:

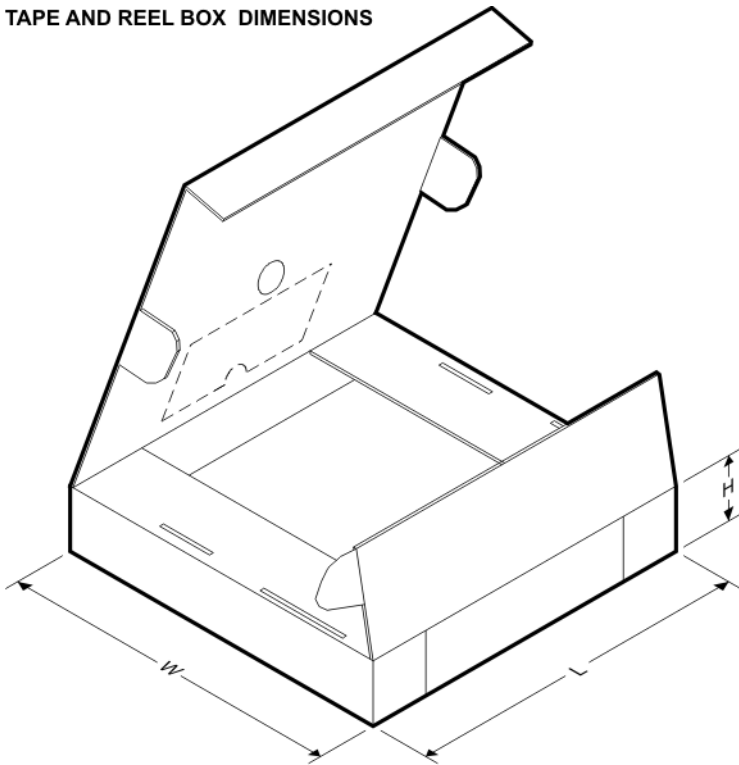
- Catalog - TI's standard catalog product
- Enhanced Product - Supports Defense, Aerospace and Medical Applications
- Military - QML certified for Military and Defense Applications

**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TLV2462QDGKRQ1	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
TLV2462QDGKRQ1	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
TLV2463AQPWRG4Q1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TLV2463QPWRG4Q1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TLV2464AQPWRG4Q1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TLV2464AQPWRQ1	TSSOP	PW	14	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TLV2462QDGKRQ1	VSSOP	DGK	8	2500	364.0	364.0	27.0
TLV2462QDGKRQ1	VSSOP	DGK	8	2500	358.0	335.0	35.0
TLV2463AQPWRG4Q1	TSSOP	PW	14	2000	367.0	367.0	35.0
TLV2463QPWRG4Q1	TSSOP	PW	14	2000	367.0	367.0	35.0
TLV2464AQPWRG4Q1	TSSOP	PW	14	2000	367.0	367.0	35.0
TLV2464AQPWRQ1	TSSOP	PW	14	2000	367.0	367.0	35.0





- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Publication IPC-7351 is recommended for alternate designs.
  - D. 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.
  - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

D (R-PDSO-G14)

PLASTIC SMALL OUTLINE

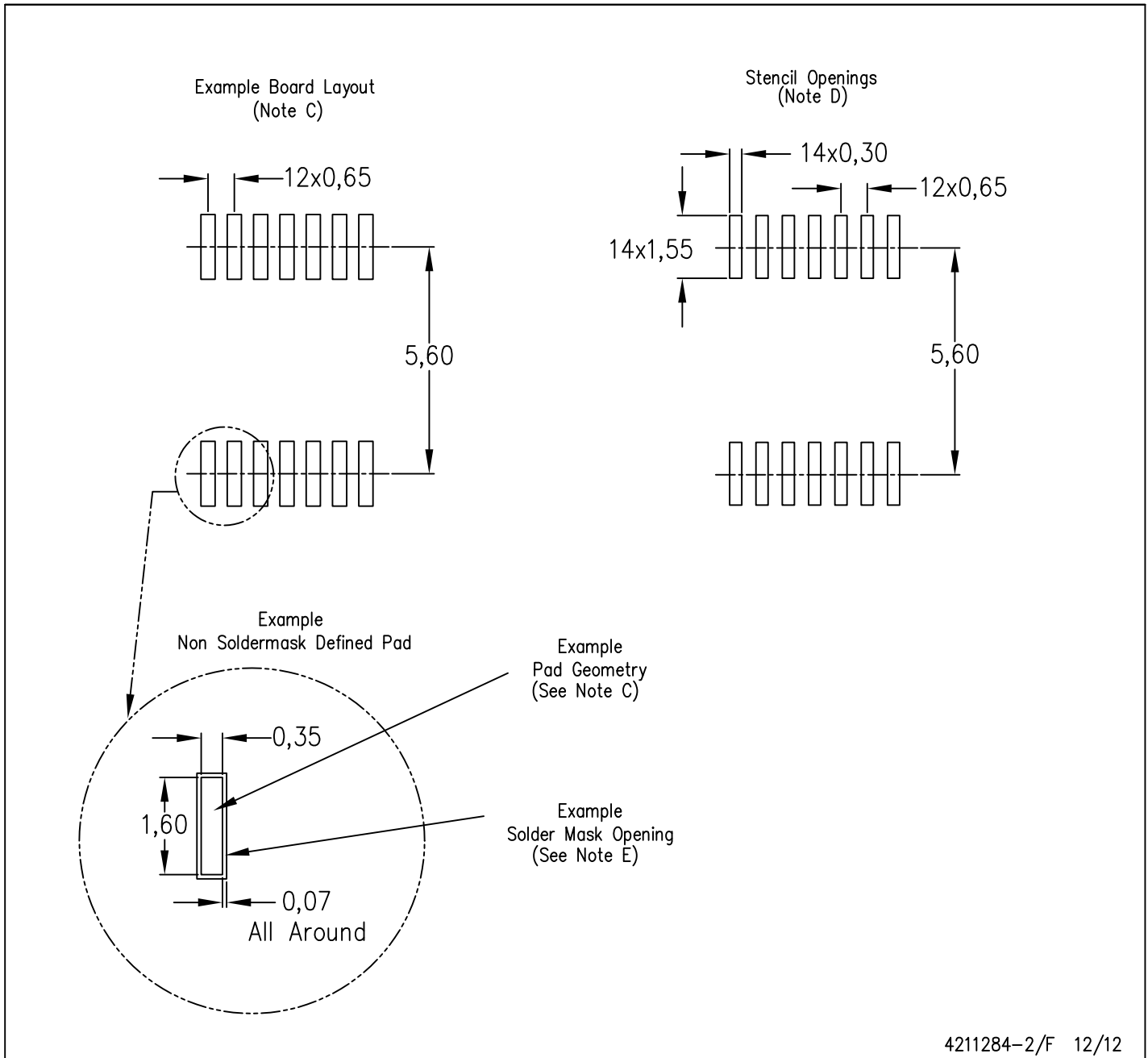


- NOTES:
- A. All linear dimensions are in inches (millimeters).
  - B. This drawing is subject to change without notice.
  -  Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
  -  Body width does not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



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.

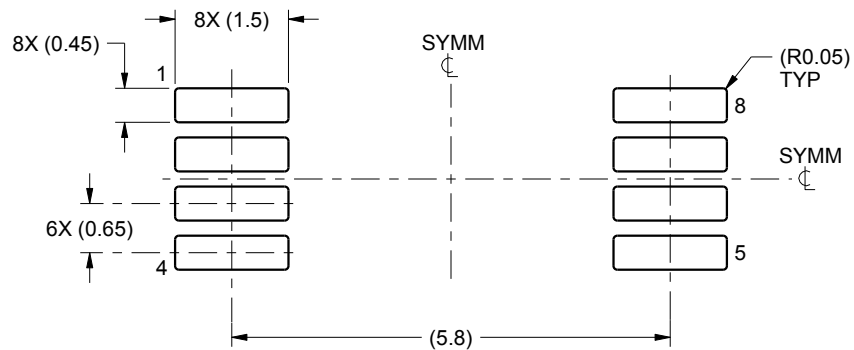


# EXAMPLE BOARD LAYOUT

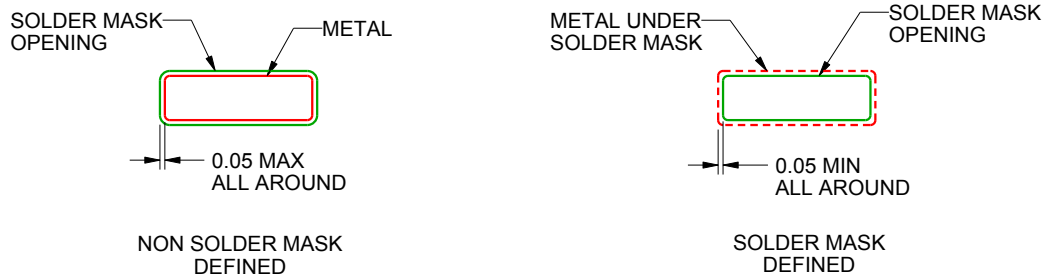
PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
SCALE:10X



SOLDER MASK DETAILS  
NOT TO SCALE

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NOTES: (continued)

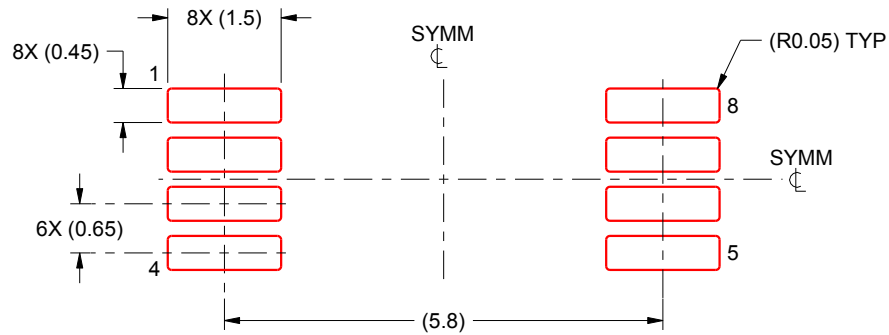
- 6. Publication IPC-7351 may have alternate designs.
- 7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

PW0008A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



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

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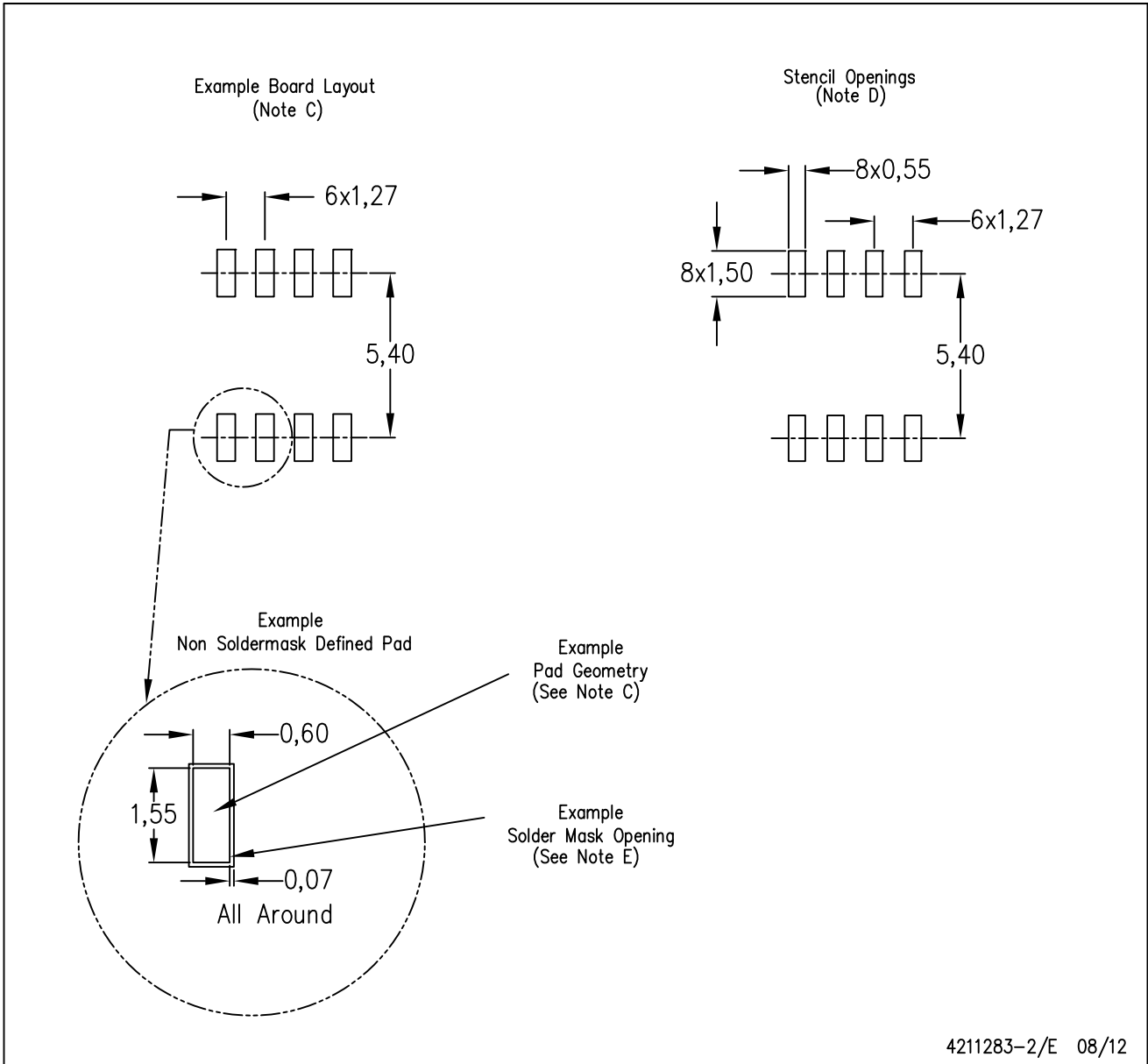
NOTES: (continued)

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



D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Publication IPC-7351 is recommended for alternate designs.
  - D. 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.
  - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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