

## TLV600x-Q1 Low-Power, Rail-to-Rail In/Out, 1-MHz Operational Amplifier for Cost-Sensitive Systems

### 1 Features

- AEC-Q100 Qualified for Automotive Applications
  - Device Temperature Grade 1:  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ,  $T_A$
  - Device HBM ESD Classification Level 3A
  - Device CDM ESD Classification Level C6
- General-Purpose Amplifiers for Cost-Sensitive Systems
- Supply Range: 1.8 V to 5.5 V
- Gain Bandwidth: 1 MHz
- Low Quiescent Current: 75  $\mu\text{A}/\text{ch}$
- Rail-to-Rail Input and Output
- Low Offset Voltage: 0.75 mV
- Unity-Gain Stable
- Input Voltage Noise Density: 28  $\text{nV}/\sqrt{\text{Hz}}$  at 1 kHz
- Internal RF and EMI Filter
- Extended Temperature Range:  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$

### 2 Applications

- Optimized for AEC-Q100 Grade 1 Applications
- Electric Vehicle Inverters
- Infotainment
- Passive Safety
- Body Electronics and Lighting

### 3 Description

The TLV600x-Q1 family of single and dual-channel operational amplifiers is specifically designed for general-purpose automotive applications. Featuring rail-to-rail input and output (RRIO) swings, low quiescent current (75  $\mu\text{A}$ , typical), wide bandwidth (1 MHz) and low noise (28  $\text{nV}/\sqrt{\text{Hz}}$  at 1 kHz), this family is attractive for a variety of automotive applications that require a good balance between cost and performance, such as infotainment, engine control units, and automotive lighting. The low-input-bias current ( $\pm 1$  pA, typical) enables the TLV600x-Q1 to be used in applications with megaohm source impedances.

The robust design of the TLV600x-Q1 provides ease-of use to the circuit designer: unity-gain stability with capacitive loads of up to 150 pF, integrated RF/EMI rejection filter, no phase reversal in overdrive conditions, and high electrostatic discharge (ESD) protection (4-kV HBM).

The devices are optimized for operation at voltages as low as 1.8 V ( $\pm 0.9$  V) and up to 5.5 V ( $\pm 2.75$  V), and are specified over the extended temperature range of  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

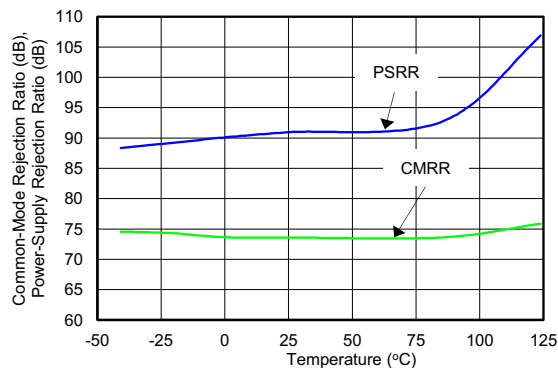
The single-channel TLV6001-Q1 is available in the SC70-5 package, and the dual-channel TLV6002-Q1 is available in both SOIC and VSSOP packages.

#### Device Information<sup>(1)</sup>

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TLV6001-Q1	SC70 (5)	2.00 mm $\times$ 1.25 mm
TLV6002-Q1	SOIC (8)	3.91 mm $\times$ 4.90 mm
	VSSOP (8)	3.00 mm $\times$ 3.00 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

#### CMRR and PSRR vs Temperature



## Table of Contents

<b>1 Features</b> .....	<b>1</b>	7.5 Input and ESD Protection .....	<b>14</b>
<b>2 Applications</b> .....	<b>1</b>	<b>8 Application and Implementation</b> .....	<b>15</b>
<b>3 Description</b> .....	<b>1</b>	8.1 Application Information.....	<b>15</b>
<b>4 Revision History</b> .....	<b>2</b>	8.2 Typical Application .....	<b>15</b>
<b>5 Pin Configuration and Functions</b> .....	<b>3</b>	8.3 System Examples .....	<b>16</b>
<b>6 Specifications</b> .....	<b>5</b>	<b>9 Power Supply Recommendations</b> .....	<b>17</b>
6.1 Absolute Maximum Ratings .....	<b>5</b>	<b>10 Layout</b> .....	<b>18</b>
6.2 ESD Ratings .....	<b>5</b>	10.1 Layout Guidelines .....	<b>18</b>
6.3 Recommended Operating Conditions.....	<b>5</b>	10.2 Layout Example: Single Channel.....	<b>18</b>
6.4 Thermal Information: TLV6001-Q1 .....	<b>6</b>	10.3 Layout Example: Dual Channel .....	<b>19</b>
6.5 Thermal Information: TLV6002-Q1 .....	<b>6</b>	<b>11 Device and Documentation Support</b> .....	<b>20</b>
6.6 Electrical Characteristics: $V_S = 1.8\text{ V to }5\text{ V } (\pm 0.9\text{ V to } \pm 2.75\text{ V})$ .....	<b>7</b>	11.1 Documentation Support .....	<b>20</b>
6.7 Typical Characteristics: Table of Graphs.....	<b>8</b>	11.2 Related Links .....	<b>20</b>
6.8 Typical Characteristics .....	<b>9</b>	11.3 Receiving Notification of Documentation Updates	<b>20</b>
<b>7 Detailed Description</b> .....	<b>12</b>	11.4 Community Resources.....	<b>20</b>
7.1 Overview .....	<b>12</b>	11.5 Trademarks .....	<b>20</b>
7.2 Functional Block Diagram .....	<b>12</b>	11.6 Electrostatic Discharge Caution.....	<b>20</b>
7.3 Feature Description.....	<b>13</b>	11.7 Glossary .....	<b>20</b>
7.4 Device Functional Modes.....	<b>14</b>	<b>12 Mechanical, Packaging, and Orderable Information</b> .....	<b>21</b>

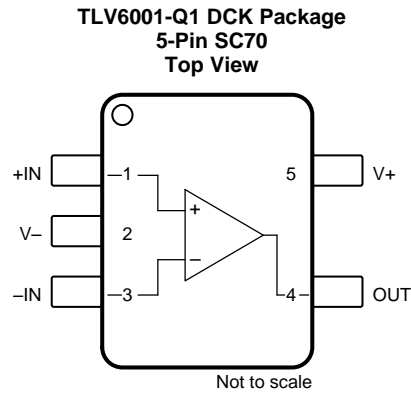
## 4 Revision History

### Changes from Original (August 2018) to Revision A

Page

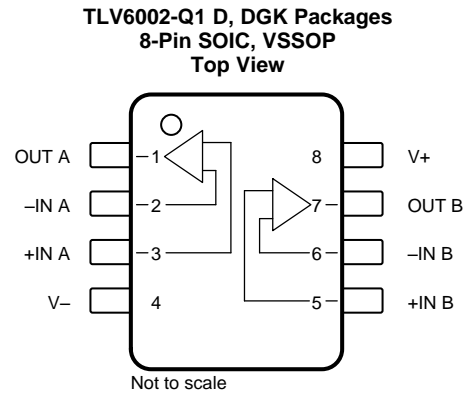
• Added TLV6002-Q1 device to data sheet.....	<b>1</b>
• Added dual channel information for TLV6002-Q1 device throughout data sheet .....	<b>1</b>
• Added ESD classification levels for TLV600x-Q1 family .....	<b>1</b>

## 5 Pin Configuration and Functions



**Pin Functions: TLV6001-Q1**

PIN		I/O	DESCRIPTION
NAME	NO.		
-IN	3	I	Inverting input
+IN	1	I	Noninverting input
OUT	4	O	Output
V-	2	—	Negative (lowest) power supply
V+	5	—	Positive (highest) power supply


**Pin Functions: TLV6002-Q1**

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

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over recommended operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

		MIN	MAX	UNIT
Voltage	Supply voltage (V+) – (V–)	7		V
	Signal input pins, voltage <sup>(2)</sup>	(V–) – 0.5	(V+) + 0.5	
Current	Signal input pins, current <sup>(2)</sup>	–10	10	mA
	Output short-circuit <sup>(3)</sup>	Continuous		
Temperature	Operating, T <sub>A</sub>	–40	150	°C
	Junction, T <sub>J</sub>	150		
	Storage, T <sub>stg</sub>	–65	150	

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) Input pins are diode-clamped to the power-supply rails. Input signals that may swing more than 0.5 V beyond the supply rails must be current limited to 10 mA or less.
- (3) Short-circuit to ground, one amplifier per package.

### 6.2 ESD Ratings

		VALUE	UNIT	
V <sub>(ESD)</sub>	Electrostatic discharge	Human-body model (HBM), per AEC Q100-002 <sup>(1)</sup> HBM ESD Classification Level 3A	±4000	V
		Charged-device model (CDM), per AEC Q100-011 CDM ESD Classification Level C4B	±1000	

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

### 6.3 Recommended Operating Conditions

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

		MIN	MAX	UNIT
V <sub>S</sub>	Supply voltage	1.8	5.5	V
T <sub>A</sub>	Specified temperature	–40	125	°C

#### 6.4 Thermal Information: TLV6001-Q1

THERMAL METRIC <sup>(1)</sup>		TLV6001-Q1	
		DCK (SC70)	
		5 PINS	
			UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	281.4	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	91.6	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	59.6	°C/W
$\Psi_{JT}$	Junction-to-top characterization parameter	1.5	°C/W
$\Psi_{JB}$	Junction-to-board characterization parameter	58.8	°C/W

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

#### 6.5 Thermal Information: TLV6002-Q1

THERMAL METRIC <sup>(1)</sup>		TLV6002-Q1		UNIT
		D (SOIC)	DGK (VSSOP)	
		8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	131.6	186.0	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	71.4	73.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	75.4	107.3	°C/W
$\Psi_{JT}$	Junction-to-top characterization parameter	22.7	14.4	°C/W
$\Psi_{JB}$	Junction-to-board characterization parameter	74.6	105.6	°C/W

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

## 6.6 Electrical Characteristics: $V_S = 1.8\text{ V to }5\text{ V }(\pm 0.9\text{ V to } \pm 2.75\text{ V})^{(1)}$

at  $T_A = 25^\circ\text{C}$ ,  $R_L = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $V_{CM} = V_{OUT} = V_S / 2$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>OFFSET VOLTAGE</b>						
$V_{OS}$	Input offset voltage			0.75	4.5	mV
$dV_{OS}/dT$	$V_{OS}$ vs temperature	$T_A = -40^\circ\text{C to }+125^\circ\text{C}$		2		$\mu\text{V}/^\circ\text{C}$
PSRR	Power-supply rejection ratio			86		dB
<b>INPUT BIAS CURRENT</b>						
$I_B$	Input bias current	$T_A = 25^\circ\text{C}$		$\pm 1$		$\mu\text{A}$
$I_{OS}$	Input offset current			$\pm 1$		$\mu\text{A}$
<b>INPUT IMPEDANCE</b>						
$Z_{ID}$	Differential			100    1		$\text{M}\Omega    \text{pF}$
$Z_{IC}$	Common-mode			1    5		$10^{13}\Omega    \text{pF}$
<b>INPUT VOLTAGE RANGE</b>						
$V_{CM}$	Common-mode voltage range	No phase reversal, rail-to-rail input	$(V-) - 0.2$		$(V+) + 0.2$	V
CMRR	Common-mode rejection ratio	$V_{CM} = -0.2\text{ V to }5.7\text{ V}$	60	76		dB
<b>OPEN-LOOP GAIN</b>						
$A_{OL}$	Open-loop voltage gain	$0.3\text{ V} < V_O < (V+) - 0.3\text{ V}$ , $R_L = 2\text{ k}\Omega$	90	110		
	Phase margin	$V_S = 5\text{ V}$ , $G = 1$		65		$^\circ$
<b>OUTPUT</b>						
$V_O$	Voltage output swing from supply rails	$R_L = 100\text{ k}\Omega$		5		mV
		$R_L = 2\text{ k}\Omega$		75	100	
$I_{SC}$	Short-circuit current			$\pm 15$		mA
$R_O$	Open-loop output impedance			2300		$\Omega$
<b>FREQUENCY RESPONSE</b>						
GBW	Gain-bandwidth product			1		MHz
SR	Slew rate			0.5		$\text{V}/\mu\text{s}$
$t_S$	Settling time	To 0.1%, $V_S = 5\text{ V}$ , 2-V step, $G = +1$		5		$\mu\text{s}$
<b>NOISE</b>						
	Input voltage noise (peak-to-peak)	$f = 0.1\text{ Hz to }10\text{ Hz}$		6		$\mu\text{V}_{PP}$
$e_n$	Input voltage noise density	$f = 1\text{ kHz}$		28		$\text{nV}/\sqrt{\text{Hz}}$
$i_n$	Input current noise density	$f = 1\text{ kHz}$		5		$\text{fA}/\sqrt{\text{Hz}}$
<b>POWER SUPPLY</b>						
$V_S$	Specified voltage range		1.8 ( $\pm 0.9$ )		5.5 ( $\pm 2.75$ )	V
$I_Q$	Quiescent current per amplifier	$I_O = 0\text{ mA}$ , $V_S = 5\text{ V}$		75	100	$\mu\text{A}$
	Power-on time	$V_S = 0\text{ V to }5\text{ V}$ , to 90% $I_Q$ level		10		$\mu\text{s}$

(1) Parameters with minimum or maximum specification limits are 100% production tested at  $25^\circ\text{C}$ , unless otherwise noted. Overtemperature limits are based on characterization and statistical analysis.

## 6.7 Typical Characteristics: Table of Graphs

**Table 1. Table of Graphs**

TITLE	FIGURE
Open-Loop Gain and Phase vs Frequency	<a href="#">Figure 1</a>
Quiescent Current vs Supply Voltage	<a href="#">Figure 2</a>
Offset Voltage Production Distribution	<a href="#">Figure 3</a>
Offset Voltage vs Common-Mode Voltage (Maximum Supply)	<a href="#">Figure 4</a>
CMRR and PSRR vs Frequency (RTI)	<a href="#">Figure 5</a>
0.1-Hz to 10-Hz Input Voltage Noise (5.5 V)	<a href="#">Figure 6</a>
Input Voltage Noise Spectral Density vs Frequency (1.8 V, 5.5 V)	<a href="#">Figure 7</a>
Input Bias and Offset Current vs Temperature	<a href="#">Figure 8</a>
Open-Loop Output Impedance vs Frequency	<a href="#">Figure 9</a>
Maximum Output Voltage vs Frequency and Supply Voltage	<a href="#">Figure 10</a>
Output Voltage Swing vs Output Current	<a href="#">Figure 11</a>
Closed-Loop Gain vs Frequency, $G = 1, -1, 10$ (1.8 V)	<a href="#">Figure 12</a>
Small-Signal Step Response, Noninverting (1.8 V)	<a href="#">Figure 13</a>
Small-Signal Step Response, Noninverting (5.5 V)	<a href="#">Figure 14</a>
Large-Signal Step Response, Noninverting (1.8 V)	<a href="#">Figure 15</a>
Large-Signal Step Response, Noninverting (5.5 V)	<a href="#">Figure 16</a>
No Phase Reversal	<a href="#">Figure 17</a>
EMIRR IN+ vs Frequency	<a href="#">Figure 18</a>



### 6.8 Typical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{ V}$ ,  $R_L = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $V_{CM} = V_{OUT} = V_S / 2$  (unless otherwise noted)

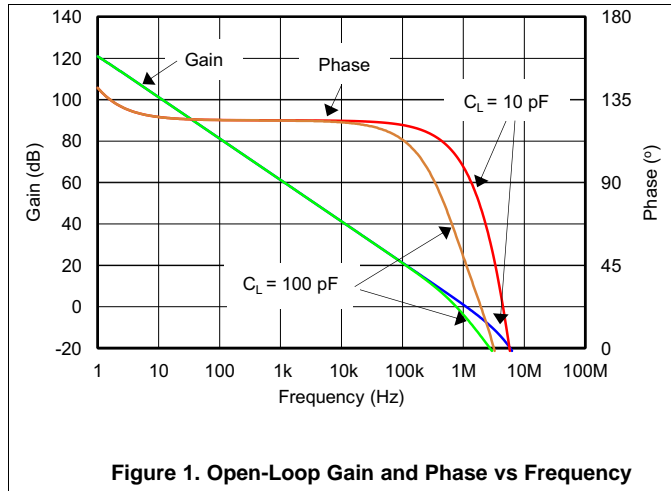


Figure 1. Open-Loop Gain and Phase vs Frequency

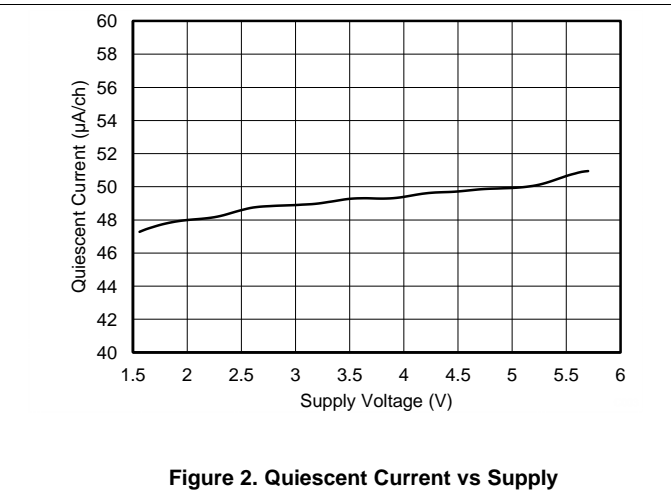


Figure 2. Quiescent Current vs Supply

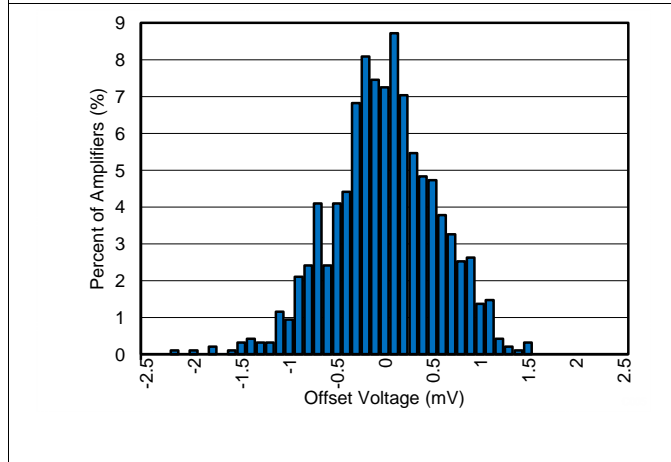


Figure 3. Offset Voltage Production Distribution

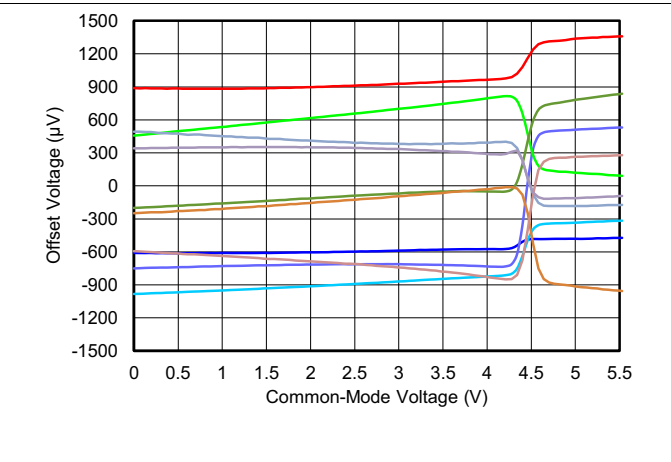


Figure 4. Offset Voltage vs Common-Mode Voltage

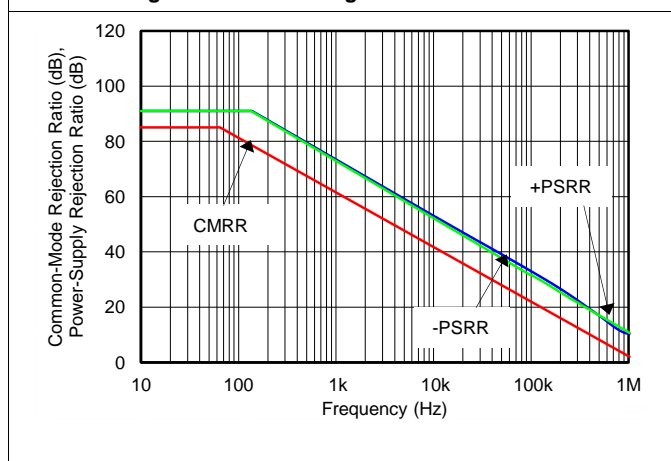


Figure 5. CMRR and PSRR vs Frequency (Referred-to-Input)

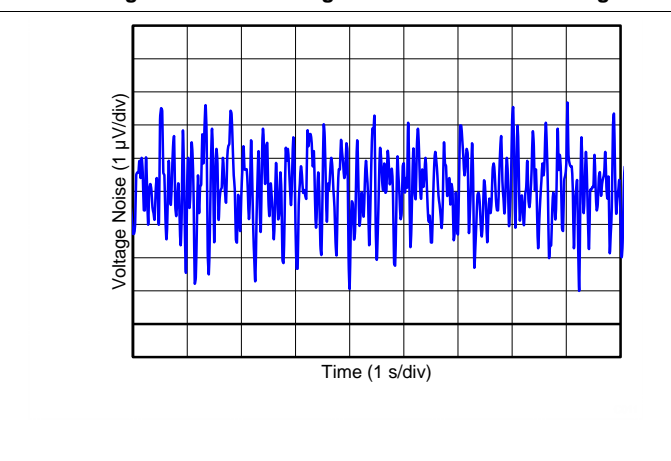


Figure 6. 0.1-Hz to 10-Hz Input Voltage Noise

### Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{ V}$ ,  $R_L = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $V_{CM} = V_{OUT} = V_S / 2$  (unless otherwise noted)

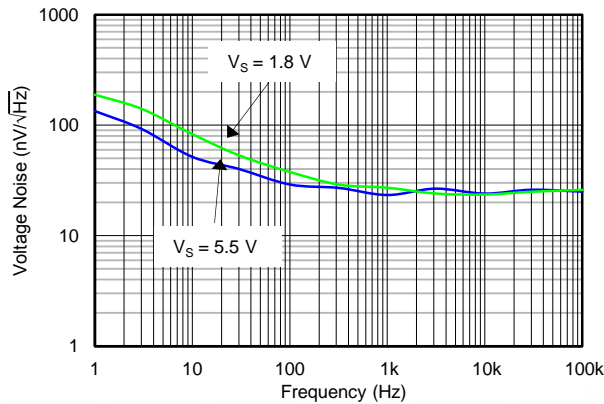


Figure 7. Input Voltage Noise Spectral Density vs Frequency

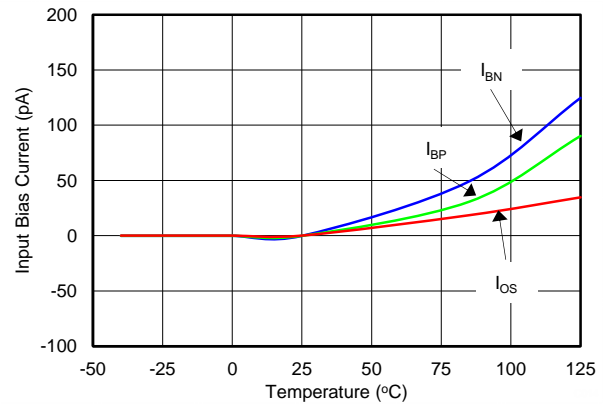


Figure 8. Input Bias and Offset Current vs Temperature

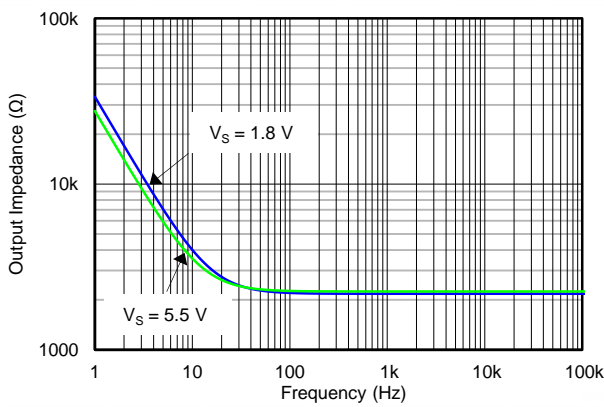


Figure 9. Open-Loop Output Impedance vs Frequency

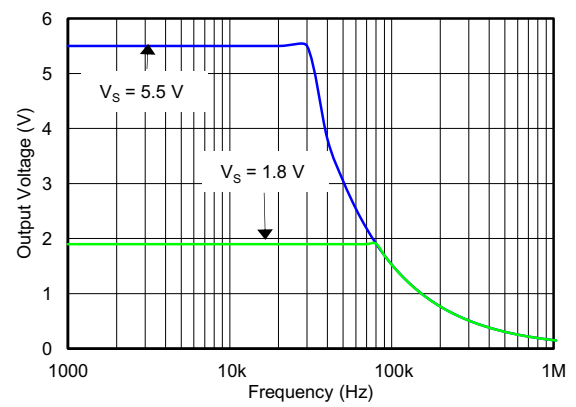


Figure 10. Maximum Output Voltage vs Frequency and Supply Voltage

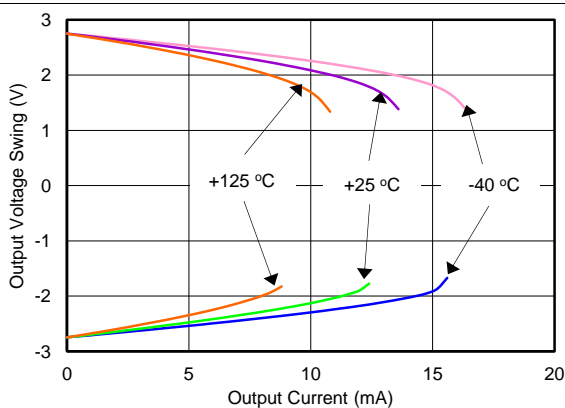


Figure 11. Output Voltage Swing vs Output Current

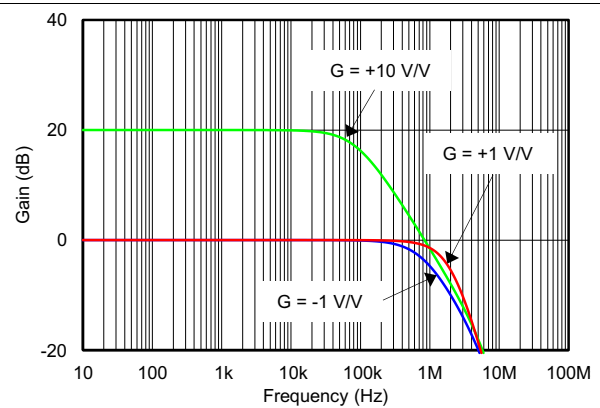


Figure 12. Closed-Loop Gain vs Frequency (Minimum Supply)

Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = 5\text{ V}$ ,  $R_L = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $V_{CM} = V_{OUT} = V_S / 2$  (unless otherwise noted)

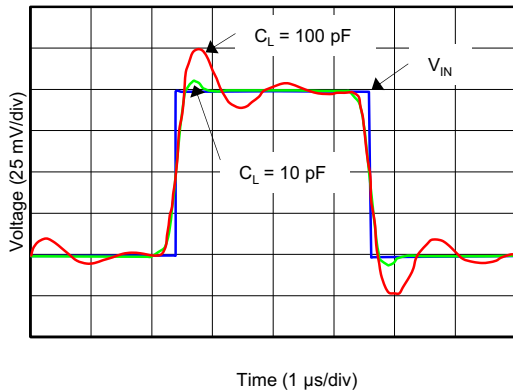


Figure 13. Small-Signal Pulse Response (Minimum Supply)

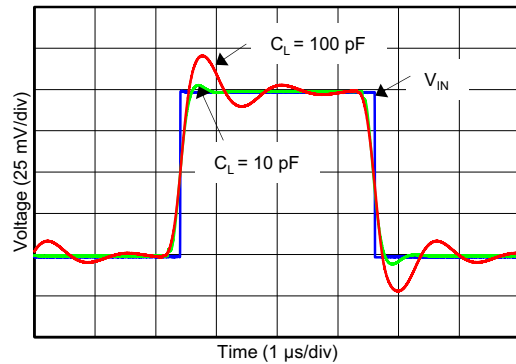


Figure 14. Small-Signal Pulse Response (Maximum Supply)

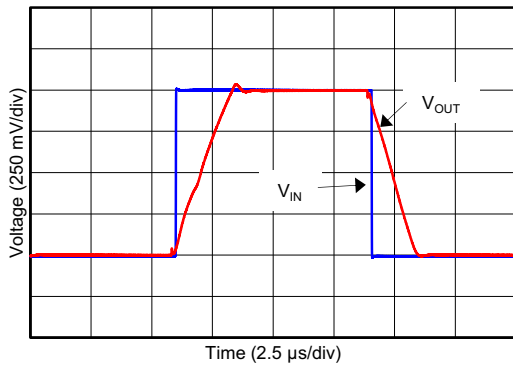


Figure 15. Large-Signal Pulse Response (Minimum Supply)

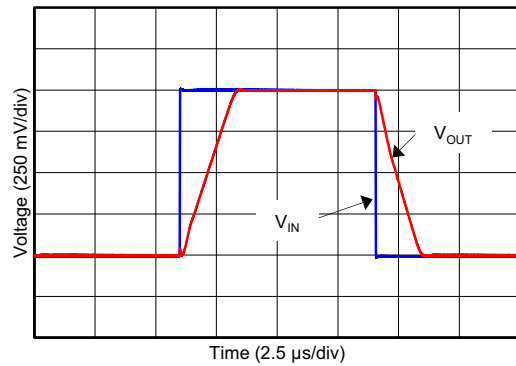


Figure 16. Large-Signal Pulse Response (Maximum Supply)

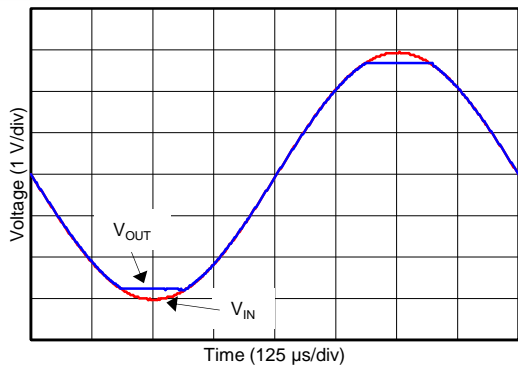


Figure 17. No Phase Reversal

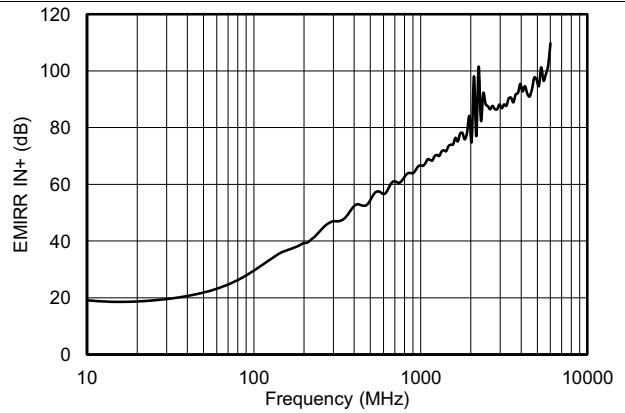


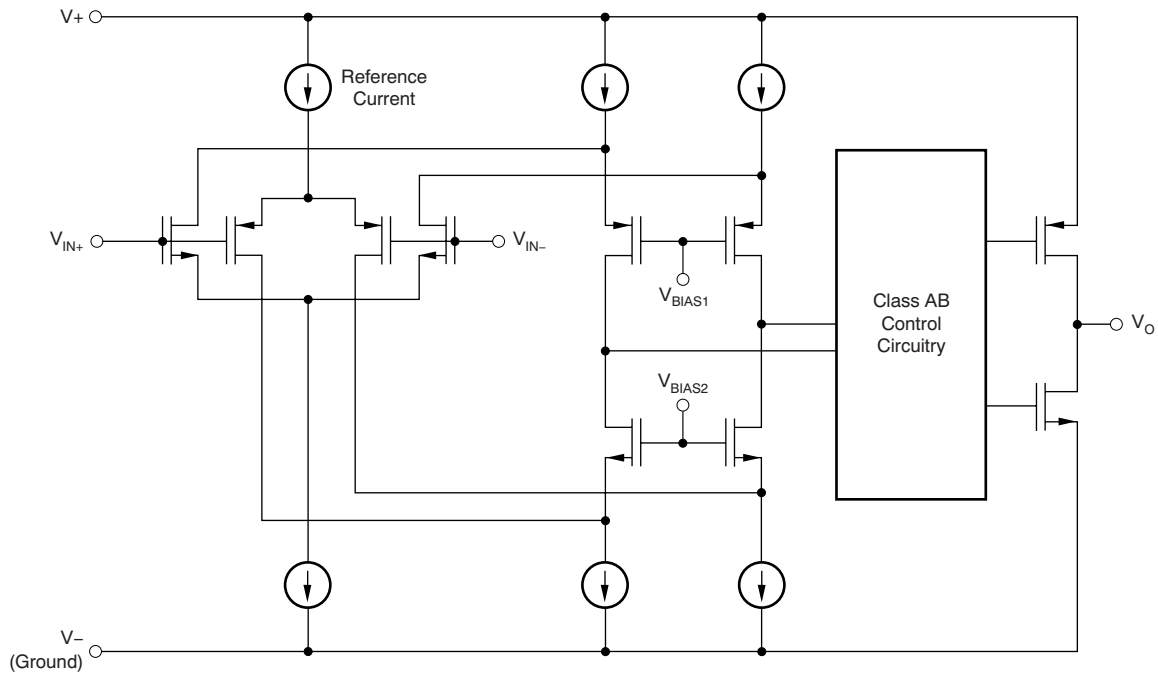
Figure 18. EMIRR IN+ vs Frequency

## 7 Detailed Description

### 7.1 Overview

The TLV600x-Q1 family of operational amplifiers is a general-purpose, low-cost family that is designed for a wide range of portable applications. Rail-to-rail input and output swings, low quiescent current, and wide dynamic range make the operational amplifier designed to drive sampling analog-to-digital converters (ADCs) and other single-supply applications.

### 7.2 Functional Block Diagram



## 7.3 Feature Description

### 7.3.1 Operating Voltage

The TLV600x-Q1 family is fully specified and tested from 1.8 V to 5.5 V ( $\pm 0.9$  V to  $\pm 2.75$  V). The [Typical Characteristics](#) section shows parameters that vary with supply voltage.

### 7.3.2 Rail-to-Rail Input

The input common-mode voltage range of the TLV600x-Q1 family extends 200 mV beyond the supply rails. This performance is achieved with a complementary input stage: an N-channel input differential pair in parallel with a P-channel differential pair, as the [Functional Block Diagram](#) section shows. The N-channel pair is active for input voltages close to the positive rail, typically  $(V+) - 1.3$  V to 200 mV above the positive supply, while the P-channel pair is on for inputs from 200 mV below the negative supply to approximately  $(V+) - 1.3$  V. There is a small transition region, typically  $(V+) - 1.4$  V to  $(V+) - 1.2$  V, in which both pairs are on. This 200-mV transition region can vary up to 300 mV with process variation. As a result, the transition region (both stages on) can range from  $(V+) - 1.7$  V to  $(V+) - 1.5$  V on the low end, and up to  $(V+) - 1.1$  V to  $(V+) - 0.9$  V on the high end. Within this transition region, PSRR, CMRR, offset voltage, offset drift, and THD can degrade compared to device operation outside this region.

### 7.3.3 Rail-to-Rail Output

Designed as a micro-power, low-noise operational amplifier, the TLV600x-Q1 family delivers a robust output drive capability. A class AB output stage with common source transistors achieve full rail-to-rail output swing capability. For resistive loads up to 100 k $\Omega$ , the output swings typically to within 5 mV of either supply rail regardless of the power supply voltage that is applied. [Figure 11](#) shows that different load conditions change the ability of the amplifier to swing close to the rails.

### 7.3.4 Common-Mode Rejection Ratio (CMRR)

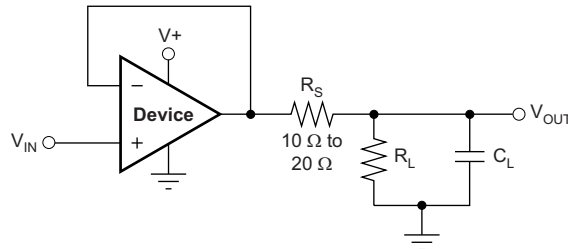
CMRR for the TLV600x-Q1 family is specified in several ways so the best match for a given application can be used; see the [Electrical Characteristics](#). First, the CMRR of the device in the common-mode range below the transition region ( $V_{CM} < (V+) - 1.3$  V) is shown. This specification is the best indicator of the capability of the device when the application requires the use of one of the differential input pairs. Second, the CMRR over the entire common-mode range is specified at ( $V_{CM} = -0.2$  V to 5.7 V). This last value includes the variations seen through the transition region, as [Figure 4](#) shows.

### 7.3.5 Capacitive Load and Stability

The TLV600x-Q1 family is designed to be used in applications where driving a capacitive load is required. As with all operational amplifiers, there can be specific instances where the TLV600x-Q1 family can become unstable. The particular op amp circuit configuration, layout, gain, and output loading are some of the factors to consider when establishing if an amplifier is stable in operation. An operational amplifier in the unity-gain (1-V/V) buffer configuration that drives a capacitive load exhibits a greater tendency for instability than an amplifier that is operated at a higher noise gain. The capacitive load in conjunction with the op amp output resistance creates a pole within the feedback loop that degrades the phase margin. The degradation of the phase margin increases as the capacitive loading increases. When operating in the unity-gain configuration, the TLV600x-Q1 family remains stable with a pure capacitive load up to approximately 1 nF. The equivalent series resistance (ESR) of some capacitors ( $C_L$  greater than 1  $\mu$ F) is sufficient to alter the phase characteristics in the feedback loop such that the amplifier remains stable. Increasing the amplifier closed-loop gain allows the amplifier to drive increasingly larger capacitance. This increased capability is evident when observing the overshoot response of the amplifier at higher voltage gains.

## Feature Description (continued)

One technique for increasing the capacitive load drive capability of the amplifier when the device operates in a unity-gain configuration is to insert a small resistor, typically  $10\ \Omega$  to  $20\ \Omega$ , in series with the output, as [Figure 19](#) shows. This resistor reduces the overshoot and ringing associated with large capacitive loads. One possible problem with this technique is that a voltage divider is created with the added series resistor and any resistor connected in parallel with the capacitive load. The voltage divider introduces a gain error at the output that reduces the output swing.



**Figure 19. Improving Capacitive Load Drive**

### 7.3.6 EMI Susceptibility and Input Filtering

Operational amplifiers vary with regard to the susceptibility of the device to electromagnetic interference (EMI). If conducted EMI enters the op amp, the dc offset observed at the amplifier output can shift from the nominal value while EMI is present. This shift is a result of signal rectification associated with the internal semiconductor junctions. While all op amp pin functions can be affected by EMI, the signal input pins are likely to be the most susceptible. The TLV600x-Q1 family incorporates an internal input low-pass filter that reduces the amplifiers response to EMI. This filter provides common-mode and differential mode filtering. The filter is designed for a cutoff frequency of approximately 35 MHz ( $-3\ \text{dB}$ ) with a rolloff of 20 dB per decade.

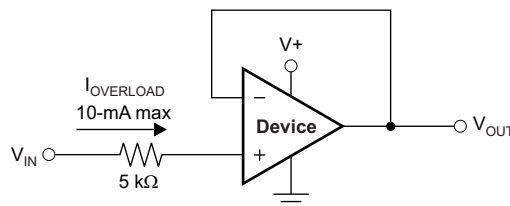
Texas Instruments developed the ability to accurately measure and quantify the immunity of an operational amplifier over a broad frequency spectrum extending from 10 MHz to 6 GHz. The EMI rejection ratio (EMIRR) metric allows op amps to be directly compared by the EMI immunity. [Figure 18](#) shows the results of this testing on the TLV600x-Q1 family. [EMI Rejection Ratio of Operational Amplifiers](#) shows detailed information, and is available for download from [www.ti.com](http://www.ti.com).

## 7.4 Device Functional Modes

The TLV600x-Q1 family has a single functional mode. The device is powered on if the power-supply voltage is between 1.8 V ( $\pm 0.9\ \text{V}$ ) and 5.5 V ( $\pm 2.75\ \text{V}$ ).

## 7.5 Input and ESD Protection

The TLV600x-Q1 family incorporates internal electrostatic discharge (ESD) protection circuits on all pins. In the case of input and output pins, this protection primarily consists of current-steering diodes connected between the input and power supply pins. The ESD protection diodes provide in-circuit, input overdrive protection if the current is limited to 10 mA, as the [Absolute Maximum Ratings](#) lists. [Figure 20](#) shows how a series input resistor can be added to the driven input to limit the input current. The added resistor contributes thermal noise at the amplifier input and the value must be kept to a minimum in noise-sensitive applications.



**Figure 20. Input Current Protection**

## 8 Application and Implementation

### NOTE

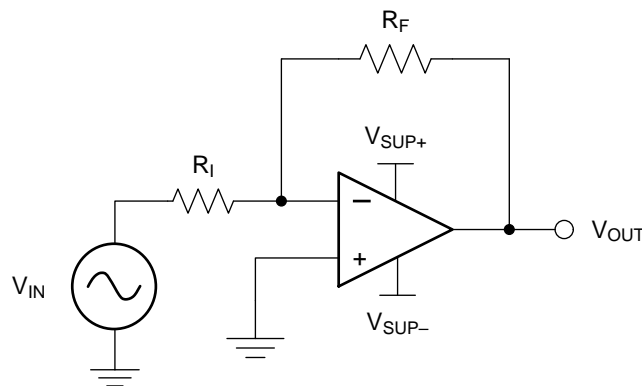
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 8.1 Application Information

The TLV600x-Q1 is a low-power, rail-to-rail input and output operational amplifier specifically designed for portable applications. The device operates from 1.8 V to 5.5 V, is unity-gain stable, and is designed for a wide range of general-purpose applications. The class AB output stage can drive  $\leq 10\text{-k}\Omega$  loads connected to any point between  $V+$  and ground. The input common-mode voltage range includes both rails and allows the TLV600x-Q1 family to be used in any single-supply application.

### 8.2 Typical Application

A typical application for an operational amplifier is an inverting amplifier, as [Figure 21](#) shows. An inverting amplifier takes a positive voltage on the input and outputs a signal inverted to the input, making a negative voltage of the same magnitude. In the same manner, the amplifier makes negative input voltages positive on the output. To add amplification, select an input resistor ( $R_I$ ) and a feedback resistor ( $R_F$ ).



**Figure 21. Application Schematic**

#### 8.2.1 Design Requirements

Select a supply voltage value that is larger than the input voltage range and the desired output range. Users must consider the limits of the input common-mode range ( $V_{CM}$ ) and the output voltage swing to the rails ( $V_O$ ). For example, this application scales a signal of  $\pm 0.5\text{ V}$  (1 V) to  $\pm 1.8\text{ V}$  (3.6 V). Setting the supply at  $\pm 2.5\text{ V}$  is sufficient to accommodate this application.

#### 8.2.2 Detailed Design Procedure

Use [Equation 1](#) and [Equation 2](#) to calculate the required gain for the inverting amplifier:

$$A_V = \frac{V_{OUT}}{V_{IN}} \tag{1}$$

$$A_V = \frac{1.8}{-0.5} = -3.6 \tag{2}$$

### Typical Application (continued)

When the desired gain is determined, select a value for  $R_I$  or  $R_F$ . Selecting a value in the kilohm range is desirable for general-purpose applications because the amplifier circuit uses currents in the milliamp range. This milliamp current range ensures the device does not draw too much current. The trade-off is that large resistors (hundreds of kilohms) draw the smallest current but generate the highest noise. Small resistors (hundreds of ohms) generate low noise but draw high current. In this example,  $R_I$  equals 10 k $\Omega$ , and  $R_F$  equals 36 k $\Omega$ . Equation 3 determines these values:

$$A_V = -\frac{R_F}{R_I} \tag{3}$$

### 8.2.3 Application Curve

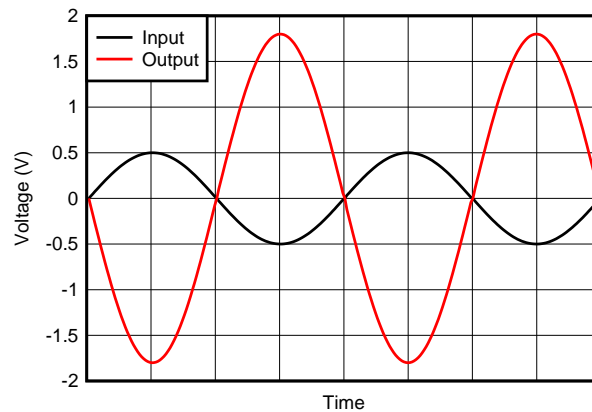
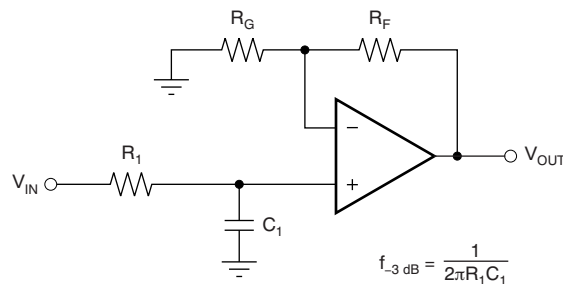


Figure 22. Inverting Amplifier Input and Output

### 8.3 System Examples

When receiving low-level signals, limiting the bandwidth of the incoming signals into the system is often required. To establish this minimum bandwidth, place an RC filter at the noninverting pin of the amplifier, as Figure 23 shows.



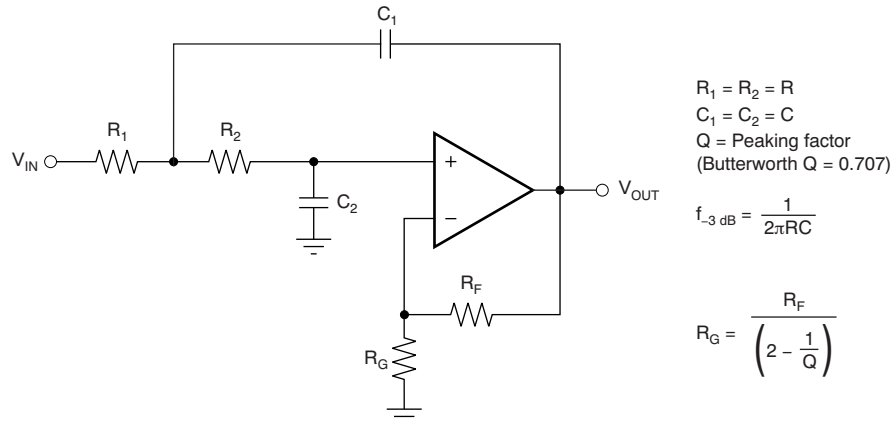
$$\frac{V_{OUT}}{V_{IN}} = \left(1 + \frac{R_F}{R_G}\right) \left(\frac{1}{1 + sR_1C_1}\right)$$

Figure 23. Single-Pole Low-Pass Filter



## System Examples (continued)

If even more attenuation is needed, a multiple pole filter is required. The Sallen-Key filter can be used for this task, as [Figure 24](#) shows. For best results, the amplifier must have a bandwidth that is 8 to 10 times larger than the filter frequency bandwidth. Failure to follow this guideline can result in phase shift of the amplifier.



**Figure 24. Two-Pole, Low-Pass, Sallen-Key Filter**

## 9 Power Supply Recommendations

The TLV600x-Q1 family is specified for operation from 1.8 V to 5.5 V ( $\pm 0.9$  V to  $\pm 2.75$  V). The [Typical Characteristics](#) section presents parameters that can exhibit significant variance with regard to operating voltage or temperature.

### CAUTION

Supply voltages larger than 7 V may permanently damage the device. (See the [Absolute Maximum Ratings](#)).

Place 0.1- $\mu$ F bypass capacitors close to the power-supply pins to reduce errors coupling in from noisy or high-impedance power supplies. For more detailed information on bypass capacitor placement, see the [Layout Guidelines](#) section.

## 10 Layout

### 10.1 Layout Guidelines

For best operational performance of the device, use good printed circuit board (PCB) layout practices, including:

- Noise can propagate into analog circuitry through the power pins of the circuit and the operational amplifier. Use bypass capacitors to reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1- $\mu$ F ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable for single-supply applications.
- Separate grounding for analog and digital portions of the circuitry is one of the simplest and most effective methods of noise suppression. One or more layers on multilayer PCBs are typically devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Take care to physically separate digital and analog grounds, paying attention to the flow of the ground current. For more detailed information, see [Circuit Board Layout Techniques](#) (available for download from [www.ti.com](http://www.ti.com)).
- To reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If the traces cannot be kept separate, crossing the sensitive trace perpendicularly is much better than crossing in parallel with the noisy trace.
- Place the external components as close to the device as possible. Keep  $R_F$  and  $R_G$  close to the inverting input in order to minimize parasitic capacitance, as shown in [Figure 25](#).
- Keep the length of input traces as short as possible. Remember that the input traces are the most sensitive part of the circuit.
- Consider a driven, low-impedance guard ring around the critical traces. A guard ring can significantly reduce leakage currents from nearby traces that are at different potentials.

### 10.2 Layout Example: Single Channel

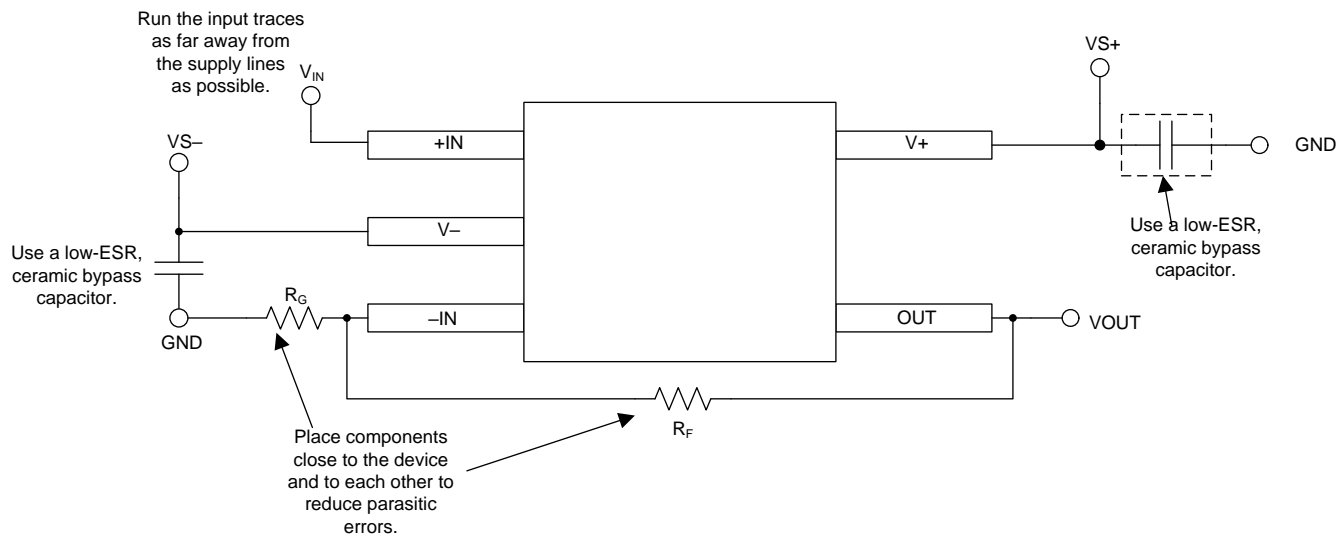


Figure 25. Operational Amplifier Board Layout for Noninverting Configuration

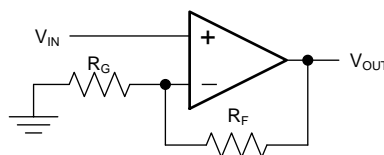
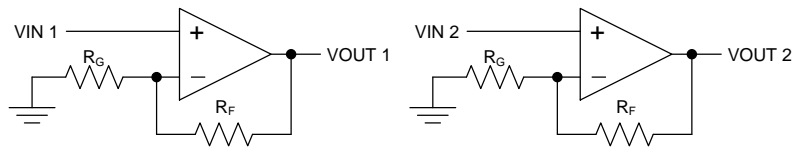
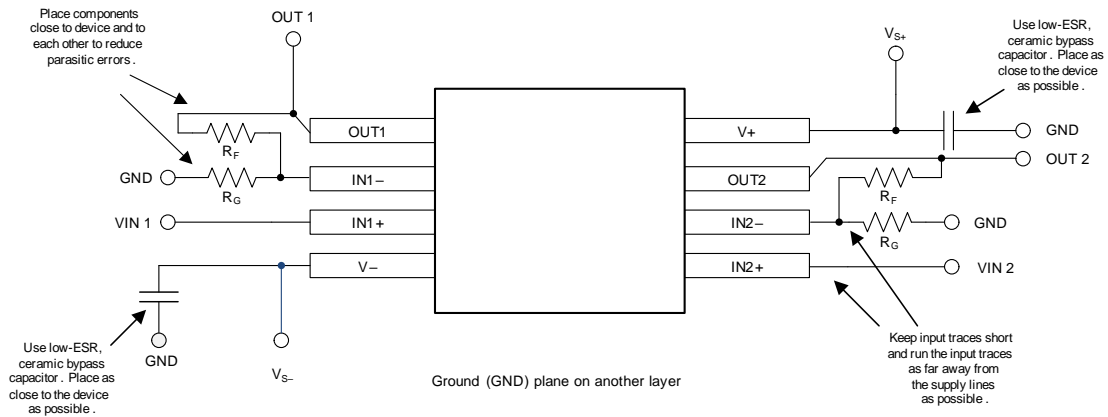


Figure 26. Schematic Representation of [Figure 25](#)

### 10.3 Layout Example: Dual Channel



**Figure 27. Schematic Representation for Figure 25**



**Figure 28. Layout Example**

## 11 Device and Documentation Support

### 11.1 Documentation Support

#### 11.1.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, [EMI Rejection Ratio of Operational Amplifiers](#)
- Texas Instruments, [Circuit Board Layout Techniques](#)

### 11.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to order now.

**Table 2. Related Links**

PARTS	PRODUCT FOLDER	ORDER NOW	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
TLV6001-Q1	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>
TLV6002-Q1	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>

### 11.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 11.4 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

### 11.5 Trademarks

E2E is a trademark of Texas Instruments.  
All other trademarks are the property of their respective owners.

### 11.6 Electrostatic Discharge Caution



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

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

### 11.7 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 12 Mechanical, Packaging, and Orderable Information

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

## PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLV6001QDCKRQ1	ACTIVE	SC70	DCK	5	3000	RoHS & Green	NIPDAUAG	Level-1-260C-UNLIM	-40 to 125	1B1	<a href="#">Samples</a>
TLV6002QDQGRQ1	ACTIVE	VSSOP	DGK	8	2500	RoHS & Green	NIPDAU   NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	1NX6	<a href="#">Samples</a>
TLV6002QDRQ1	ACTIVE	SOIC	D	8	2500	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	V6002Q	<a href="#">Samples</a>

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(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.

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

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

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

**OTHER QUALIFIED VERSIONS OF TLV6001-Q1, TLV6002-Q1 :**

- Catalog : [TLV6001](#), [TLV6002](#)

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

**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
TLV6001QDCKRQ1	SC70	DCK	5	3000	180.0	8.4	2.47	2.3	1.25	4.0	8.0	Q3
TLV6002QDGRQ1	VSSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
TLV6002QDRQ1	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	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)
TLV6001QDCKRQ1	SC70	DCK	5	3000	183.0	183.0	20.0
TLV6002QDQKRQ1	VSSOP	DGK	8	2500	366.0	364.0	50.0
TLV6002QDRQ1	SOIC	D	8	2500	353.0	353.0	32.0

# DCK0005A



## PACKAGE OUTLINE

SOT - 1.1 max height

SMALL OUTLINE TRANSISTOR



4214834/G 11/2024

### NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC MO-203.
4. Support pin may differ or may not be present.
5. Lead width does not comply with JEDEC.
6. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25mm per side

# EXAMPLE BOARD LAYOUT

DCK0005A

SOT - 1.1 max height

SMALL OUTLINE TRANSISTOR



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:18X



SOLDER MASK DETAILS

4214834/G 11/2024

NOTES: (continued)

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

# EXAMPLE STENCIL DESIGN

DCK0005A

SOT - 1.1 max height

SMALL OUTLINE TRANSISTOR



SOLDER PASTE EXAMPLE  
BASED ON 0.125 THICK STENCIL  
SCALE:18X

4214834/G 11/2024

NOTES: (continued)

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



D0008A

# PACKAGE OUTLINE

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

NOTES:

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

# EXAMPLE BOARD LAYOUT

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE  
 EXPOSED METAL SHOWN  
 SCALE:8X



SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

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

# EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



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

4214825/C 02/2019

NOTES: (continued)

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

# DGK0008A



# PACKAGE OUTLINE

VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



4214862/A 04/2023

**NOTES:**

PowerPAD is a trademark of Texas Instruments.

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-187.



# EXAMPLE BOARD LAYOUT

DGK0008A

™ VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 15X



SOLDER MASK DETAILS

4214862/A 04/2023

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
9. Size of metal pad may vary due to creepage requirement.

# EXAMPLE STENCIL DESIGN

DGK0008A

™ VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE  
SCALE: 15X

4214862/A 04/2023

NOTES: (continued)

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

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

Copyright © 2025, Texas Instruments Incorporated