OPAx992-Q1 Automotive, 40-V Rail-to-Rail Input or Output, Low Offset Voltage, Low Noise Op Amp

1 Features

- AEC-Q100 qualified for automotive applications
  - Temperature grade 1: –40°C to +125°C, $T_A$
  - Device HBM ESD classification level 2A
  - Device CDM ESD classification level C6
- Low offset voltage: ±210 µV
- Low offset voltage drift: ±0.25 µV/°C
- Low noise: 7 nV/$\sqrt{\text{Hz}}$ at 1 kHz, 4.4 nV/$\sqrt{\text{Hz}}$ broadband
- High common-mode rejection: 115 dB
- Low bias current: ±10 pA
- Rail-to-rail input and output
- MUX-friendly/comparator inputs
  - Amplifier operates with differential inputs up to supply rail
  - Amplifier can be used in open-loop or as comparator
- Wide bandwidth: 10.6-MHz GBW, unity-gain stable
- High slew rate: 32 V/µs
- Low quiescent current: 2.4 mA per amplifier
- Wide supply: ±1.35 V to ±20 V, 2.7 V to 40 V
- Robust EMI/RR performance

2 Applications

- Automotive head unit
- Automotive external amplifier
- Emergency call (eCall)
- Telematics control unit (TCU)
- Traction inverter
- HEV/EV on-board and wireless charger (OBC)
- HEV/EV DC/DC converter
- High-side and low-side current sensing

3 Description

The OPAx992-Q1 family (OPA992-Q1, OPA2992-Q1, and OPA4992-Q1) is a family of high voltage (40 V) general purpose operational amplifiers. These devices offer excellent DC precision and AC performance, including rail-to-rail input or output, low offset (±210 µV, typical), low offset drift (±0.25 µV/°C, typical) and low noise (7 nV/$\sqrt{\text{Hz}}$ at 1 kHz, 4.4 nV/$\sqrt{\text{Hz}}$ at 10 kHz).

Features such as differential and common-mode input voltage ranges to the supply rails, high short-circuit current (±65 mA), and high slew rate (32 V/µs) make the OPAx992-Q1 a flexible, robust, and high-performance op amp for high-voltage automotive applications.

The OPAx992-Q1 family of op amps is available in standard packages (such as SOIC, TSSOP, VSSOP, SOT-23, and SC70), and is specified from –40°C to 125°C.

Package Information

<table>
<thead>
<tr>
<th>PART NUMBER(1)</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPA992-Q1</td>
<td>DCK (SC70, 5)</td>
<td>2.00 mm × 1.25 mm</td>
</tr>
<tr>
<td></td>
<td>DBV (SOT-23, 5)</td>
<td>2.90 mm × 1.60 mm</td>
</tr>
<tr>
<td>OPA2992-Q1</td>
<td>DGK (VSSOP, 8)</td>
<td>3.00 mm × 3.00 mm</td>
</tr>
<tr>
<td></td>
<td>D (SOIC, 8)</td>
<td>4.90 mm × 3.90 mm</td>
</tr>
<tr>
<td>OPA4992-Q1</td>
<td>PW (TSSOP, 14)</td>
<td>5.00 mm × 4.40 mm</td>
</tr>
<tr>
<td></td>
<td>D (SOIC, 14)</td>
<td>8.65 mm × 3.90 mm</td>
</tr>
</tbody>
</table>

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

OPAx992-Q1 in Current-Sensing Applications

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An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. UNLESS OTHERWISE NOTED, this document contains PRODUCTION DATA.
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4 Revision History
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (February 2023) to Revision D (April 2023) Page
  • Changed the status of the 14-pin SOIC (D) and TSSOP (PW) packages from: Preview to: Active .............. 1

Changes from Revision B (January 2023) to Revision C (February 2023) Page
  • Changed the status of the 5-pin SOT-23 and 8-pin SOIC package from: Preview to: Active ..................... 1

Changes from Revision A (December 2022) to Revision B (January 2023) Page
  • Deleted the preview tag for the SC70-5 (DCK) package ................................................................. 1
  • Added OPA992-Q1 to the ESD Ratings section .......................................................... 6
  • Changed the values in the Thermal Information table ................................................................. 7
  • Changed the max room temp offset voltage in Electrical Characteristics section from 1 mV to 1.03 mV ........ 8

Changes from Revision * (August 2022) to Revision A (December 2022) Page
  • Changed the device status from Advance Information to ProdMix ............................................. 1
  • Deleted the preview tag for the VSSOP-8 (DGK) package .......................................................... 1
5 Pin Configuration and Functions

Figure 5-1. OPA992-Q1 DBV Package, 5-Pin SOT-23 (Top View)

Figure 5-2. OPA992-Q1 DCK Package, 5-Pin SC70 (Top View)

Table 5-1. Pin Functions: OPA992-Q1

<table>
<thead>
<tr>
<th>PIN</th>
<th>TYPE(1)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN+</td>
<td>I</td>
<td>Noninverting input</td>
</tr>
<tr>
<td>IN–</td>
<td>I</td>
<td>Inverting input</td>
</tr>
<tr>
<td>OUT</td>
<td>O</td>
<td>Output</td>
</tr>
<tr>
<td>V+</td>
<td>—</td>
<td>Positive (highest) power supply</td>
</tr>
<tr>
<td>V–</td>
<td>—</td>
<td>Negative (lowest) power supply</td>
</tr>
</tbody>
</table>

(1) I = input, O = output
Table 5-2. Pin Functions: OPA2992-Q1

<table>
<thead>
<tr>
<th>PIN</th>
<th>TYPE(1)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN1+</td>
<td>3</td>
<td>I Noninverting input, channel 1</td>
</tr>
<tr>
<td>IN1-</td>
<td>2</td>
<td>I Inverting input, channel 1</td>
</tr>
<tr>
<td>IN2+</td>
<td>5</td>
<td>I Noninverting input, channel 2</td>
</tr>
<tr>
<td>IN2-</td>
<td>6</td>
<td>I Inverting input, channel 2</td>
</tr>
<tr>
<td>OUT1</td>
<td>1</td>
<td>O Output, channel 1</td>
</tr>
<tr>
<td>OUT2</td>
<td>7</td>
<td>O Output, channel 2</td>
</tr>
<tr>
<td>V+</td>
<td>8</td>
<td>— Positive (highest) power supply</td>
</tr>
<tr>
<td>V-</td>
<td>4</td>
<td>— Negative (lowest) power supply</td>
</tr>
</tbody>
</table>

(1)  I = input, O = output
Figure 5-4. OPA4992-Q1 D and PW Package, 14-Pin SOIC and TSSOP (Top View)

Table 5-3. Pin Functions: OPA4992-Q1

<table>
<thead>
<tr>
<th>NAME</th>
<th>NO.</th>
<th>TYPE(1)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN1+</td>
<td>3</td>
<td>I</td>
<td>Noninverting input, channel 1</td>
</tr>
<tr>
<td>IN1–</td>
<td>2</td>
<td>I</td>
<td>Inverting input, channel 1</td>
</tr>
<tr>
<td>IN2+</td>
<td>5</td>
<td>I</td>
<td>Noninverting input, channel 2</td>
</tr>
<tr>
<td>IN2–</td>
<td>6</td>
<td>I</td>
<td>Inverting input, channel 2</td>
</tr>
<tr>
<td>IN3+</td>
<td>10</td>
<td>I</td>
<td>Noninverting input, channel 3</td>
</tr>
<tr>
<td>IN3–</td>
<td>9</td>
<td>I</td>
<td>Inverting input, channel 3</td>
</tr>
<tr>
<td>IN4+</td>
<td>12</td>
<td>I</td>
<td>Noninverting input, channel 4</td>
</tr>
<tr>
<td>IN4–</td>
<td>13</td>
<td>I</td>
<td>Inverting input, channel 4</td>
</tr>
<tr>
<td>OUT1</td>
<td>1</td>
<td>O</td>
<td>Output, channel 1</td>
</tr>
<tr>
<td>OUT2</td>
<td>7</td>
<td>O</td>
<td>Output, channel 2</td>
</tr>
<tr>
<td>OUT3</td>
<td>8</td>
<td>O</td>
<td>Output, channel 3</td>
</tr>
<tr>
<td>OUT4</td>
<td>14</td>
<td>O</td>
<td>Output, channel 4</td>
</tr>
<tr>
<td>V+</td>
<td>4</td>
<td>—</td>
<td>Positive (highest) power supply</td>
</tr>
<tr>
<td>V–</td>
<td>11</td>
<td>—</td>
<td>Negative (lowest) power supply</td>
</tr>
</tbody>
</table>

(1) I = input, O = output
6 Specifications

6.1 Absolute Maximum Ratings

over operating ambient temperature range (unless otherwise noted)(1)

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage, (V_s = (V^+) – (V^-))</td>
<td>0</td>
<td>42</td>
<td>V</td>
</tr>
<tr>
<td>Signal input pins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common-mode voltage(3)</td>
<td>((V^-) – 0.5)</td>
<td>((V^+) + 0.5)</td>
<td>V</td>
</tr>
<tr>
<td>Differential voltage(3)</td>
<td>(V_s + 0.2)</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Current(3)</td>
<td>–10</td>
<td>10</td>
<td>mA</td>
</tr>
<tr>
<td>Output short-circuit(2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating ambient temp.</td>
<td>(-55)</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Junction temp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage temp.</td>
<td>(-65)</td>
<td>150</td>
<td>°C</td>
</tr>
</tbody>
</table>

(1) Operating the device beyond the ratings listed under **Absolute Maximum Ratings** will cause permanent damage to the device. These are stress ratings only, based on process and design limitations, and this device has not been designed to function outside the conditions indicated under **Recommended Operating Conditions**. Exposure to any condition outside **Recommended Operating Conditions** for extended periods, including absolute-maximum-rated conditions, may affect device reliability and performance.

(2) Short-circuit to ground, one amplifier per package. Extended short-circuit current, especially with higher supply voltage, can cause excessive heating and eventual destruction.

(3) 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.

6.2 ESD Ratings

<table>
<thead>
<tr>
<th></th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPA992-Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrostatic discharge</td>
<td>±2000</td>
<td>V</td>
</tr>
<tr>
<td>Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charged-device model (CDM), per ANSI/ESDA/JEDEC JS-002(2)</td>
<td>±1500</td>
<td></td>
</tr>
<tr>
<td>OPA2992-Q1 and OPA4992-Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrostatic discharge</td>
<td>±2500</td>
<td>V</td>
</tr>
<tr>
<td>Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charged-device model (CDM), per ANSI/ESDA/JEDEC JS-002(2)</td>
<td>±1500</td>
<td></td>
</tr>
</tbody>
</table>

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating ambient temperature range (unless otherwise noted)

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_s)</td>
<td>2.7</td>
<td>40</td>
<td>V</td>
</tr>
<tr>
<td>(V_i)</td>
<td>((V^-))</td>
<td>((V^+))</td>
<td>V</td>
</tr>
<tr>
<td>(T_a)</td>
<td>–40</td>
<td>125</td>
<td>°C</td>
</tr>
</tbody>
</table>

Product Folder Links: OPA992-Q1 OPA2992-Q1 OPA4992-Q1
6.4 Thermal Information for Single Channel

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>OPA992-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DBV (SOT-23)</td>
<td>DCK (SC70)</td>
</tr>
<tr>
<td>$R_{JA}$</td>
<td>189.3</td>
<td>202.4</td>
</tr>
<tr>
<td>$R_{JC(top)}$</td>
<td>86.8</td>
<td>111.6</td>
</tr>
<tr>
<td>$R_{JB}$</td>
<td>55.9</td>
<td>51.6</td>
</tr>
<tr>
<td>$\psi_{JT}$</td>
<td>23.6</td>
<td>25.8</td>
</tr>
<tr>
<td>$\psi_{JB}$</td>
<td>55.5</td>
<td>51.4</td>
</tr>
</tbody>
</table>

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report, SPRA953.

6.5 Thermal Information for Dual Channel

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>OPA2992-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D (SOIC)</td>
<td>DGK (VSSOP)</td>
</tr>
<tr>
<td>$R_{JA}$</td>
<td>130.8</td>
<td>173.9</td>
</tr>
<tr>
<td>$R_{JC(top)}$</td>
<td>74.0</td>
<td>65.7</td>
</tr>
<tr>
<td>$R_{JB}$</td>
<td>74.3</td>
<td>95.6</td>
</tr>
<tr>
<td>$\psi_{JT}$</td>
<td>25.8</td>
<td>10.9</td>
</tr>
<tr>
<td>$\psi_{JB}$</td>
<td>73.5</td>
<td>94.1</td>
</tr>
</tbody>
</table>

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report, SPRA953.

6.6 Thermal Information for Quad Channel

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>OPA4992-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D (SOIC)</td>
<td>PW (TSSOP)</td>
</tr>
<tr>
<td>$R_{JA}$</td>
<td>94.9</td>
<td>120.0</td>
</tr>
<tr>
<td>$R_{JC(top)}$</td>
<td>51.1</td>
<td>50.4</td>
</tr>
<tr>
<td>$R_{JB}$</td>
<td>51.4</td>
<td>63.1</td>
</tr>
<tr>
<td>$\psi_{JT}$</td>
<td>15.3</td>
<td>8.1</td>
</tr>
<tr>
<td>$\psi_{JB}$</td>
<td>51.0</td>
<td>62.5</td>
</tr>
</tbody>
</table>

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report, SPRA953.
### 6.7 Electrical Characteristics

For $V_S = (V+) - (V-) = 2.7$ V to 40 V ($\pm 1.35$ V to $\pm 20$ V) at $T_A = 25^\circ$C, $R_L = 10$ kΩ connected to $V_S / 2$, $V_{CM} = V_S / 2$, and $V_{OUT} = V_S / 2$, unless otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFFSET VOLTAGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{OS}$</td>
<td>Input offset voltage</td>
<td>$V_{CM} = V-$</td>
<td>±0.21</td>
<td>±1.03</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to 125$^\circ$C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$dV_{OS}/dT$</td>
<td>Input offset voltage drift</td>
<td>$V_{CM} = V-$</td>
<td>±0.25</td>
<td></td>
<td>μV/°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to 125$^\circ$C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSRR</td>
<td>Input offset voltage versus power supply</td>
<td>OPA992-Q1, OPA2992-Q1, OPA4992-Q1, $V_{CM} = V-$, $V_S = 5$ V to 40 V</td>
<td>±0.2</td>
<td>±1.3</td>
<td>μV/V</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to 125$^\circ$C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OPA992-Q1, OPA2992-Q1, OPA4992-Q1, $V_{CM} = V-$, $V_S = 2.7$ V to 40 V$^{(1)}$</td>
<td>±0.4</td>
<td>±1.8</td>
<td>μV/V</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to 125$^\circ$C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DC channel separation</td>
<td>0.4</td>
<td></td>
<td>μV/V</td>
</tr>
</tbody>
</table>

### INPUT BIAS CURRENT

- $I_B$: Input bias current ±10 pA
- $I_{OS}$: Input offset current ±10 pA

### NOISE

- $E_{in}$: Input voltage noise $f = 0.1$ Hz to 10 Hz 2.77 μV $\text{pp}$
- $E_{in}$: Input voltage noise $f = 1$ kHz 0.49 μV $\text{rms}$
- $E_{n}$: Input voltage noise density $f = 1$ kHz 7 nV/$\sqrt{\text{Hz}}$
- $E_{n}$: Input voltage noise density $f = 10$ kHz 4.4 nV/$\sqrt{\text{Hz}}$

### INPUT VOLTAGE RANGE

- $V_{CM}$: Common-mode voltage range $(V-) \leq V_{CM} < (V+) - 2$ V (PMOS pair) 100 115 V
- $V_{CM}$: Common-mode voltage range $(V-) + 0.1$ V $< V_{CM} < (V+) - 0.1$ V 75 98 V
- $V_{CM}$: Common-mode voltage range $(V+) - 2$ V $< V_{CM} < (V+) - 1$ V 79 dB

### CMRR

- $V_S = 40$ V, $V_{CM} = V_S / 2$, $(V-) + 0.1$ V $< V_O < (V+) - 0.1$ V 120 142 dB
- $V_S = 5$ V, $V_{CM} = V_S / 2$, $(V-) + 0.12$ V $< V_O < (V+) - 0.12$ V 142 dB
- $V_S = 2.7$ V, $V_{CM} = V_S / 2$, $(V-) + 0.1$ V $< V_O < (V+) - 0.1$ V$^{(1)}$ 104 125 dB

### OPEN-LOOP GAIN

- $A_{OL}$: Open-loop voltage gain $V_S = 40$ V, $V_{CM} = V_S / 2$, $(V-) + 0.1$ V $< V_O < (V+) - 0.1$ V 120 142 dB
- $V_S = 5$ V, $V_{CM} = V_S / 2$, $(V-) + 0.12$ V $< V_O < (V+) - 0.12$ V 142 dB
- $V_S = 2.7$ V, $V_{CM} = V_S / 2$, $(V-) + 0.1$ V $< V_O < (V+) - 0.1$ V$^{(1)}$ 104 125 dB

**Notes:**
- $V_{CM}$ is defined as the midpoint between $V_+$ and $V_-$. The common-mode rejection ratio (CMRR) is the ratio of the output voltage swing at the common-mode input voltage to the output voltage swing at the differential input voltage.
- $A_{OL}$ is the open-loop voltage gain, which is the ratio of the output voltage to the input voltage for an open-loop amplifier.

The data is subject to change without notice. For the most current data, please refer to the TI website.
6.7 Electrical Characteristics (continued)

For \( V_S = (V^+) - (V^-) = 2.7 \text{ V to } 40 \text{ V (±1.35 V to ±20 V)} \) at \( T_A = 25^\circ \text{C} \), \( R_L = 10 \text{ k}\Omega \) connected to \( V_S / 2 \), \( V_{CM} = V_S / 2 \), and \( V_{OUT} = V_S / 2 \), unless otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>GBW</td>
<td>Gain-bandwidth product</td>
<td>10.6</td>
<td>MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>Slew rate</td>
<td></td>
<td>32</td>
<td>V/\mu s</td>
<td></td>
</tr>
<tr>
<td>( t_s )</td>
<td>Settling time</td>
<td></td>
<td>0.65</td>
<td>\mu s</td>
<td></td>
</tr>
<tr>
<td>( t_s )</td>
<td></td>
<td></td>
<td>0.3</td>
<td>\mu s</td>
<td></td>
</tr>
<tr>
<td>Phase margin</td>
<td>( G = +1, R_L = 10 \text{ k}\Omega, C_L = 20 \text{ pF} )</td>
<td>64</td>
<td>°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overload recovery time</td>
<td>( V_N \times \text{gain} &gt; V_S )</td>
<td>170</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THD+N</td>
<td>Total harmonic distortion + noise</td>
<td></td>
<td>0.00005%</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>( V_S = 40 \text{ V}, V_O = 3 \text{ V}_{RMS}, G = 1, f = 1 \text{ kHz}, R_L = 10 \text{ k}\Omega )</td>
<td>126</td>
<td>dB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_S = 10 \text{ V}, V_O = 3 \text{ V}_{RMS}, G = 1, f = 1 \text{ kHz}, R_L = 128 \text{ \Omega} )</td>
<td>90</td>
<td>dB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_S = 10 \text{ V}, V_O = 0.4 \text{ V}_{RMS}, G = 1, f = 1 \text{ kHz}, R_L = 32 \text{ \Omega} )</td>
<td>0.00032%</td>
<td>dB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OUTPUT</td>
<td>Voltage output swing from rail</td>
<td></td>
<td>7</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>( V_S = 40 \text{ V}, R_L = \text{no load} )</td>
<td>48</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_S = 40 \text{ V}, R_L = 10 \text{ k}\Omega )</td>
<td>220</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_S = 2.7 \text{ V}, R_L = \text{no load} )</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_S = 2.7 \text{ V}, R_L = 10 \text{ k}\Omega )</td>
<td>5</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_S = 2.7 \text{ V}, R_L = 2 \text{ k}\Omega )</td>
<td>20</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( I_{SC} )</td>
<td>Short-circuit current</td>
<td>±65(2)</td>
<td>mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( C_{LOAD} )</td>
<td>Capacitive load drive</td>
<td>See Phase Margin vs Capacitive Load</td>
<td>pF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( Z_O )</td>
<td>Open-loop output impedance</td>
<td>( I_O = 0 \text{ A} )</td>
<td>See Open-Loop Output Impedance vs Frequency</td>
<td>\Omega</td>
<td></td>
</tr>
<tr>
<td>POWER SUPPLY</td>
<td>Quiescent current per amplifier</td>
<td>( \text{OPA}992-Q1, \text{OPA}4992-Q1, I_O = 0 \text{ A} )</td>
<td>2.4</td>
<td>2.8</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>( T_A = –40^\circ \text{C to 125^\circ} \text{C} )</td>
<td>2.84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \text{OPA}992-Q1, I_O = 0 \text{ A} )</td>
<td>2.48</td>
<td>2.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( T_A = –40^\circ \text{C to 125^\circ} \text{C} )</td>
<td>2.98</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Specified by characterization only.
(2) At high supply voltage, placing the \( \text{OPA}x992-Q1 \) in a sudden short to mid-supply or ground leads to rapid thermal shutdown. Output current greater than \( I_{SC} \) can be achieved if rapid thermal shutdown is avoided as per Output Voltage Swing vs Output Current.
(3) See Slew Rate vs Input Step Voltage for more information.
6.8 Typical Characteristics

at \( T_A = 25^\circ C, V_S = \pm 20 V, V_{CM} = V_S / 2, R_{LOAD} = 10 \, k\Omega \) (unless otherwise noted)

![Figure 6-1. Offset Voltage Production Distribution](image1)

![Figure 6-2. Offset Voltage Drift Distribution](image2)

![Figure 6-3. Offset Voltage vs Temperature](image3)

![Figure 6-4. Offset Voltage vs Temperature](image4)

![Figure 6-5. Offset Voltage vs Common-Mode Voltage](image5)

![Figure 6-6. Offset Voltage vs Common-Mode Voltage (Transition Region)](image6)
6.8 Typical Characteristics (continued)

at $T_A = 25^\circ C$, $V_S = \pm 20$ V, $V_{CM} = V_S / 2$, $R_{LOAD} = 10$ kΩ (unless otherwise noted)

Figure 6-7. Offset Voltage vs Common-Mode Voltage

Figure 6-8. Offset Voltage vs Common-Mode Voltage (Transition Region)

Figure 6-9. Offset Voltage vs Common-Mode Voltage

Figure 6-10. Offset Voltage vs Common-Mode Voltage (Transition Region)

Figure 6-11. Offset Voltage vs Power Supply

Figure 6-12. Closed-Loop Gain vs Frequency
6.8 Typical Characteristics (continued)

at $T_A = 25^\circ C$, $V_S = \pm 20 \text{ V}$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10 \text{ k\Omega}$ (unless otherwise noted)

![Graph of Input Bias Current and Offset Current vs Common-Mode Voltage](image1)

![Graph of Input Bias Current and Offset Current vs Temperature](image2)

![Graph of Slew Rate vs Input Step Voltage](image3)

![Graph of Output Voltage Swing vs Output Current (Sourcing)](image4)

![Graph of Output Voltage Swing vs Output Current (Sinking)](image5)

![Graph of Output Voltage Swing vs Output Current (Sinking)](image6)
6.8 Typical Characteristics (continued)

at $T_A = 25°C$, $V_S = \pm 20$ V, $V_{CM} = V_S/2$, $R_{LOAD} = 10 \, k\Omega$ (unless otherwise noted)

---

**Figure 6-19. Output Voltage Swing vs Output Current (Sinking)**

**Figure 6-20. CMRR and PSRR vs Frequency**

**Figure 6-21. CMRR vs Temperature**

**Figure 6-22. CMRR vs Temperature**

**Figure 6-23. CMRR vs Temperature**

**Figure 6-24. PSRR vs Temperature**
6.8 Typical Characteristics (continued)

at $T_A = 25°C$, $V_S = \pm 20$ V, $V_{CM} = V_S / 2$, $R_{LOAD} = 10 \, k\Omega$ (unless otherwise noted)

---

**Figure 6-25. 0.1-Hz to 10-Hz Noise**

**Figure 6-26. Input Voltage Noise Spectral Density vs Frequency**

**Figure 6-27. Quiescent Current vs Supply Voltage**

**Figure 6-28. Quiescent Current vs Temperature**

**Figure 6-29. Open-Loop Voltage Gain vs Temperature (dB)**

**Figure 6-30. Open-Loop Output Impedance vs Frequency**
6.8 Typical Characteristics (continued)

at $T_A = 25^\circ C$, $V_S = \pm 20 \, V$, $V_{CM} = V_S / 2$, $R_{LOAD} = 10 \, k\Omega$ (unless otherwise noted)

Figure 6-31. Small-Signal Overshoot vs Capacitive Load

Figure 6-32. Small-Signal Overshoot vs Capacitive Load

Figure 6-33. Phase Margin vs Capacitive Load

Figure 6-34. No Phase Reversal

Figure 6-35. Positive Overload Recovery

Figure 6-36. Negative Overload Recovery
6.8 Typical Characteristics (continued)

at $T_A = 25^\circ C$, $V_S = \pm 20$ V, $V_{CM} = V_S / 2$, $R_{LOAD} = 10$ k$\Omega$ (unless otherwise noted)

**Figure 6-37. Small-Signal Step Response**

- $C_L = 20$ pF, $G = 1$, 20-mV$_{pp}$ step response

**Figure 6-38. Small-Signal Step Response**

- $C_L = 20$ pF, $G = -1$, 20-mV$_{pp}$ step response

**Figure 6-39. Large-Signal Step Response**

- $C_L = 20$ pF, $G = 1$, 5-V$_{pp}$ step response

**Figure 6-40. Large-Signal Step Response**

- $C_L = 20$ pF, $G = -1$, 5-V$_{pp}$ step response

**Figure 6-41. Maximum Output Voltage vs Frequency**

**Figure 6-42. Channel Separation vs Frequency**

- $V_S = 40$ V
- $V_S = 16$ V
- $V_S = 2.7$ V

- Frequency (Hz)
- Crosstalk (dB)
- Output (V)

OPA992-Q1, OPA2992-Q1, OPA4992-Q1

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Product Folder Links: OPA992-Q1 OPA2992-Q1 OPA4992-Q1
6.8 Typical Characteristics (continued)

at \( T_A = 25°C \), \( V_S = \pm 20 \text{ V} \), \( V_{CM} = V_S / 2 \), \( R_{LOAD} = 10 \text{ kΩ} \) (unless otherwise noted)

![Graph showing EMIRR vs Frequency](Figure 6-43. EMIRR (Electromagnetic Interference Rejection Ratio) vs Frequency)
7 Detailed Description

7.1 Overview

The OPAx992-Q1 family (OPA992-Q1, OPA2992-Q1, and OPA4992-Q1) is a family of high voltage (40 V) general purpose operational amplifiers.

These devices offer excellent DC precision and AC performance, including rail-to-rail input or output, low offset (±210 µV, typical), and low offset drift (±0.25 µV/°C, typical).

Special features such as differential and common-mode input voltage range to the supply rail, high short-circuit current (±65 mA), and high slew rate (32 V/µs) make the OPAx992-Q1 an extremely flexible, robust, and high-performance operational amplifier for high-voltage automotive applications.

7.2 Functional Block Diagram
7.3 Feature Description

7.3.1 Input Protection Circuitry

The OPAx992-Q1 uses a special input architecture to eliminate the requirement for input protection diodes but still provides robust input protection under transient conditions. Figure 7-1 shows conventional input diode protection schemes that are activated by fast transient step responses and introduce signal distortion and settling time delays because of alternate current paths, as shown in Figure 7-2. For low-gain circuits, these fast-ramping input signals forward-bias back-to-back diodes, causing an increase in input current and resulting in extended settling time.

![Figure 7-1. OPAx992-Q1 Input Protection Does Not Limit Differential Input Capability](image)

![Figure 7-2. Back-to-Back Diodes Create Settling Issues](image)

The OPAx992-Q1 family of operational amplifiers provides a true high-impedance differential input capability for high-voltage applications using a patented input protection architecture that does not introduce additional signal distortion or delayed settling time, making the device an excellent op amp for multichannel, high-switched, input applications. The OPAx992-Q1 tolerates a maximum differential swing (voltage between inverting and non-inverting pins of the op amp) of up to 40 V, making the device designed for use as a comparator or in applications with fast-ramping input signals such as data-acquisition systems; see the TI TechNote MUX-Friendly Precision Operational Amplifiers for more information.
### 7.3.2 EMI Rejection

The OPAx992-Q1 uses integrated electromagnetic interference (EMI) filtering to reduce the effects of EMI from sources such as wireless communications and densely-populated boards with a mix of analog signal chain and digital components. EMI immunity can be improved with circuit design techniques; the OPAx992-Q1 benefits from these design improvements. Texas Instruments has 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. Figure 7-3 shows the results of this testing on the OPAx992-Q1. Table 7-1 provides the EMIRR IN+ values for the OPAx992-Q1 at particular frequencies commonly encountered in real-world applications. The *EMI Rejection Ratio of Operational Amplifiers* application report contains detailed information on the topic of EMIRR performance relating to op amps and is available for download from [www.ti.com](http://www.ti.com).

![Figure 7-3. EMIRR Testing](image)

**Table 7-1. OPAx992-Q1 EMIRR IN+ For Frequencies of Interest**

<table>
<thead>
<tr>
<th>FREQUENCY</th>
<th>APPLICATION OR ALLOCATION</th>
<th>EMIRR IN+</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 MHz</td>
<td>Mobile radio, mobile satellite, space operation, weather, radar, ultra-high frequency (UHF) applications</td>
<td>50.0 dB</td>
</tr>
<tr>
<td>900 MHz</td>
<td>Global system for mobile communications (GSM) applications, radio communication, navigation, GPS (to 1.6 GHz), GSM, aeronautical mobile, UHF applications</td>
<td>56.3 dB</td>
</tr>
<tr>
<td>1.8 GHz</td>
<td>GSM applications, mobile personal communications, broadband, satellite, L-band (1 GHz to 2 GHz)</td>
<td>65.6 dB</td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>802.11b, 802.11g, 802.11n, Bluetooth®, mobile personal communications, industrial, scientific and medical (ISM) radio band, amateur radio and satellite, S-band (2 GHz to 4 GHz)</td>
<td>70.0 dB</td>
</tr>
<tr>
<td>3.6 GHz</td>
<td>Radiolocation, aero communication and navigation, satellite, mobile, S-band</td>
<td>78.9 dB</td>
</tr>
<tr>
<td>5 GHz</td>
<td>802.11a, 802.11n, aero communication and navigation, mobile communication, space and satellite operation, C-band (4 GHz to 8 GHz)</td>
<td>91.0 dB</td>
</tr>
</tbody>
</table>
7.3.3 Thermal Protection

The internal power dissipation of any amplifier causes the internal (junction) temperature to rise. This phenomenon is called self heating. The absolute maximum junction temperature of the OPAx992-Q1 is 150°C. Exceeding this temperature causes damage to the device. The OPAx992-Q1 has a thermal protection feature that reduces damage from self heating. The protection works by monitoring the temperature of the device and turning off the op amp output drive for temperatures above 170°C. Figure 7-4 shows an application example for the OPA2992-Q1 that has significant self heating because of the power dissipation (0.954 W). In this example, both channels have a quiescent power dissipation while one of the channels has a significant load. Thermal calculations indicate that for an ambient temperature of 55°C, the device junction temperature reaches 180°C. The actual device, however, turns off the output drive to recover towards a safe junction temperature. Figure 7-4 shows how the circuit behaves during thermal protection. During normal operation, the device acts as a buffer so the output is 3 V. When self heating causes the device junction temperature to increase above the internal limit, the thermal protection forces the output to a high-impedance state and the output is pulled to ground through resistor $R_L$. If the condition that caused excessive power dissipation is not removed, then the amplifier oscillates between a shutdown and enabled state until the output fault is corrected. Please note that thermal performance can vary greatly depending on the package selected and the PCB layout design. This example uses the thermal performance of the SOIC (8) package.

![Figure 7-4. Thermal Protection](image)

7.3.4 Capacitive Load and Stability

The OPAx992-Q1 features an output stage capable of driving moderate capacitive loads, and by leveraging an isolation resistor, the device can easily be configured to drive larger capacitive loads. Increasing the gain enhances the ability of the amplifier to drive greater capacitive loads; see Figure 7-5 and Figure 7-6. The particular op amp circuit configuration, layout, gain, and output loading are some of the factors to consider when establishing whether an amplifier are stable in operation.

![Figure 7-5. Small-Signal Overshoot vs Capacitive Load (20-mVpp Output Step, G = +1)](image)

![Figure 7-6. Small-Signal Overshoot vs Capacitive Load (20-mVpp Output Step, G = -1)](image)
For additional drive capability in unity-gain configurations, improve capacitive load drive by inserting a small resistor, $R_{ISO}$, in series with the output, as shown in Figure 7-7. This resistor significantly reduces ringing and maintains DC performance for purely capacitive loads. However, if a resistive load is in parallel with the capacitive load, then a voltage divider is created, thus introducing a gain error at the output and slightly reducing the output swing. The error introduced is proportional to the ratio $R_{ISO} / R_L$ and is generally negligible at low output levels. A high capacitive load drive makes the OPAx992-Q1 an excellent choice for applications such as reference buffers, MOSFET gate drives, and cable-shield drives. The circuit shown in Figure 7-7 uses an isolation resistor, $R_{ISO}$, to stabilize the output of an op amp. $R_{ISO}$ modifies the open-loop gain of the system for increased phase margin.

![Figure 7-7. Extending Capacitive Load Drive With the OPA992-Q1](image-url)
### 7.3.5 Common-Mode Voltage Range

The OPAx992-Q1 is a 40-V, true rail-to-rail input operational amplifier with an input common-mode range that extends to both supply rails. This wide range is achieved with paralleled complementary N-channel and P-channel differential input pairs, as shown in Figure 7-8. The N-channel pair is active for input voltages close to the positive rail, typically from \((V^+)-1\) V to the positive supply. The P-channel pair is active for inputs from the negative supply to approximately \((V^+)-2\) V. There is a small transition region, typically \((V^+)-2\) V to \((V^+)-1\) V, in which both input pairs are on. This transition region can vary modestly with process variation. Within this region PSRR, CMRR, offset voltage, offset drift, noise, and THD performance may be degraded compared to operation outside this region.

Figure 6-5 shows this transition region for a typical device in terms of input voltage offset in more detail.

For more information on common-mode voltage range and PMOS/NMOS pair interaction, see *Op Amps With Complementary-Pair Input Stages* application note.

![Figure 7-8. Rail-to-Rail Input Stage](image)

### 7.3.6 Phase Reversal Protection

The OPAx992-Q1 family has internal phase-reversal protection. Many op amps exhibit a phase reversal when the input is driven beyond the linear common-mode range. This condition is most often encountered in non-inverting circuits when the input is driven beyond the specified common-mode voltage range, causing the output to reverse into the opposite rail. The OPAx992-Q1 is a rail-to-rail input op amp; therefore, the common-mode range can extend up to the rails. Input signals beyond the rails do not cause phase reversal; instead, the output limits into the appropriate rail. Figure 7-9 shows this performance. For more information on phase reversal, see *Op Amps With Complementary-Pair Input Stages* application note.

![Figure 7-9. No Phase Reversal](image)
7.3.7 Electrical Overstress

Designers often ask questions about the capability of an operational amplifier to withstand electrical overstress (EOS). These questions tend to focus on the device inputs, but can involve the supply voltage pins or even the output pin. Each of these different pin functions have electrical stress limits determined by the voltage breakdown characteristics of the particular semiconductor fabrication process and specific circuits connected to the pin. Additionally, internal electrostatic discharge (ESD) protection is built into these circuits to protect them from accidental ESD events both before and during product assembly.

Having a good understanding of this basic ESD circuitry and the relevance to an electrical overstress event is helpful. Figure 7-10 shows the ESD circuits contained in the OPAx992-Q1 (indicated by the dashed line area). The ESD protection circuitry involves several current-steering diodes connected from the input and output pins and routed back to the internal power-supply lines, where the diodes meet at an absorption device or the power-supply ESD cell, internal to the operational amplifier. This protection circuitry is intended to remain inactive during normal circuit operation.

![Figure 7-10. Equivalent Internal ESD Circuitry Relative to a Typical Circuit Application](image)

An ESD event is very short in duration and very high voltage (for example, 1 kV, 100 ns), whereas an EOS event is long duration and lower voltage (for example, 50 V, 100 ms). The ESD diodes are designed for out-of-circuit ESD protection (that is, during assembly, test, and storage of the device before being soldered to the PCB). During an ESD event, the ESD signal is passed through the ESD steering diodes to an absorption circuit (labeled ESD power-supply circuit). The ESD absorption circuit clamps the supplies to a safe level.

Although this behavior is necessary for out-of-circuit protection, excessive current and damage is caused if activated in-circuit. A transient voltage suppressors (TVS) can be used to prevent against damage caused by turning on the ESD absorption circuit during an in-circuit ESD event. Using the appropriate current limiting resistors and TVS diodes allows for the use of device ESD diodes to protect against EOS events.
7.3.8 Overload Recovery

Overload recovery is defined as the time required for the op amp output to recover from a saturated state to a linear state. The output devices of the op amp enter a saturation region when the output voltage exceeds the rated operating voltage, either due to the high input voltage or the high gain. After the device enters the saturation region, the charge carriers in the output devices require time to return back to the linear state. After the charge carriers return back to the linear state, the device begins to slew at the specified slew rate. Thus, the propagation delay in case of an overload condition is the sum of the overload recovery time and the slew time. The overload recovery time for the OPAx992-Q1 is approximately 170 ns.

7.3.9 Typical Specifications and Distributions

Designers often have questions about a typical specification of an amplifier to design a more robust circuit. Due to natural variation in process technology and manufacturing procedures, every specification of an amplifier exhibits some amount of deviation from the ideal value, like an amplifier's input offset voltage. These deviations often follow Gaussian (bell curve), or normal distributions, and circuit designers can leverage this information to guardband their system, even when there is not a minimum or maximum specification in Section 6.7.

Figure 7-11. Ideal Gaussian Distribution

Figure 7-11 shows an example distribution, where \( \mu \), or \( mu \), is the mean of the distribution, and where \( \sigma \), or \( sigma \), is the standard deviation of a system. For a specification that exhibits this kind of distribution, approximately two-thirds (68.26%) of all units can be expected to have a value within one standard deviation, or one sigma, of the mean (from \( \mu - \sigma \) to \( \mu + \sigma \)).

Depending on the specification, values listed in the typical column of the Section 6.7 table are represented in different ways. As a general rule, if a specification naturally has a nonzero mean (for example, like gain bandwidth), then the typical value is equal to the mean (\( \mu \)). However, if a specification naturally has a mean near zero (like input offset voltage), then the typical value is equal to the mean plus one standard deviation (\( \mu + \sigma \)) to most accurately represent the typical value.
This chart can be used to calculate approximate probability of a specification in a unit; for example, for OPAx992-Q1, the typical input voltage offset is 210 µV. So 68.2% of all OPAx992-Q1 devices are expected to have an offset from –210 µV to +210 µV. At 4 σ (±840 µV), 99.9937% of the distribution has an offset voltage less than ±840 µV, which means 0.0063% of the population is outside of these limits, which corresponds to about 1 in 15,873 units.

Specifications with a value in the minimum or maximum column are specified by TI, and units outside these limits are removed from production material. For example, the OPAx992-Q1 family has a maximum offset voltage of 1 mV at 25°C, and even though this corresponds to slightly less than 5 σ (≅1 in 1.7 million units), which is extremely unlikely, TI maintains that any unit with larger offset than 1 mV is removed from production material.

For specifications with no value in the minimum or maximum column, consider selecting a sigma value of sufficient guardband for the application, and design worst-case conditions using this value. For example, the 6-σ value corresponds to about 1 in 500 million units, which is an extremely unlikely chance, and can be an option as a wide guardband to design a system around. In this case, the OPAx992-Q1 family does not have a maximum or minimum for offset voltage drift. But based on the typical value of 0.25 µV/°C in the Section 6.7 table, the 6-σ value for offset voltage drift is about 1.5 µV/°C when calculated. When designing for worst-case system conditions, this value can be used to estimate the worst possible offset across temperature without having an actual minimum or maximum value.

Note that process variation and adjustments over time can shift typical means and standard deviations, and unless there is a value in the minimum or maximum specification column, TI cannot verify the performance of a device. This information must be used only to estimate the performance of a device.

7.4 Device Functional Modes

The OPAx992-Q1 has a single functional mode and is operational when the power-supply voltage is greater than or equal to 2.7 V (±1.35 V). The maximum power supply voltage for the OPAx992-Q1 is 40 V (±20 V).
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, as well as validating and testing their design implementation to confirm system functionality.

8.1 Application Information

The OPAx992-Q1 family offers excellent DC precision and AC performance. These devices operate up to 40-V supply rails and offer true rail-to-rail input or output, low offset voltage and offset voltage drift, as well as 10.6-MHz bandwidth and high output drive. These features make the OPAx992-Q1 a robust, high-performance operational amplifier for high-voltage automotive applications.

8.2 Typical Applications

8.2.1 Low-Side Current Measurement

Figure 8-1 shows the OPA992-Q1 configured in a low-side current sensing application. For a full analysis of the circuit shown in Figure 8-1 including theory, calculations, simulations, and measured data, see TI Precision Design TIPD129, 0-A to 1-A Single-Supply Low-Side Current-Sensing Solution.

8.2.1.1 Design Requirements

The design requirements for this design are:

- Load current: 0 A to 1 A
- Max output voltage: 4.9 V
- Maximum shunt voltage: 100 mV

8.2.1.2 Detailed Design Procedure

The transfer function of the circuit in Figure 8-1 is given in Equation 1:

\[ V_{OUT} = I_{LOAD} \times R_{SHUNT} \times Gain \]  

(1)
The load current ($I_{LOAD}$) produces a voltage drop across the shunt resistor ($R_{SHUNT}$). The load current is set from 0 A to 1 A. To keep the shunt voltage below 100 mV at maximum load current, the largest shunt resistor is defined using Equation 2:

$$R_{SHUNT} = \frac{V_{SHUNT\_MAX}}{I_{LOAD\_MAX}} = \frac{100 \text{ mV}}{1 \text{ A}} = 100 \text{ mΩ}$$  \hspace{1cm} (2)

Using Equation 2, $R_{SHUNT}$ is calculated to be 100 mΩ. The voltage drop produced by $I_{LOAD}$ and $R_{SHUNT}$ is amplified by the OPA992-Q1 to produce an output voltage of 0 V to 4.9 V. The gain needed by the OPA992-Q1 to produce the necessary output voltage is calculated using Equation 3:

$$Gain = \frac{V_{OUT\_MAX} - V_{OUT\_MIN}}{(V_{IN\_MAX} - V_{IN\_MIN})}$$  \hspace{1cm} (3)

Using Equation 3, the required gain is calculated to be 49 V/V, which is set with resistors $R_F$ and $R_G$. Equation 4 is used to size the resistors, $R_F$ and $R_G$, to set the gain of the OPA992-Q1 to 49 V/V.

$$Gain = 1 + \left(\frac{R_F}{R_G}\right)$$  \hspace{1cm} (4)

Choosing $R_F$ as 5.76 kΩ, $R_G$ is calculated to be 120 Ω. $R_F$ and $R_G$ were chosen as 5.76 kΩ and 120 Ω because the values are standard value resistors that create a 49:1 ratio. Other resistors that create a 49:1 ratio can also be used. However, excessively large resistors generate thermal noise that exceeds the intrinsic noise of the op amp. Figure 8-2 shows the measured transfer function of the circuit shown in Figure 8-1.

### 8.2.1.3 Application Curve

![Figure 8-2. Low-Side, Current-Sense, Transfer Function](image)

### 8.3 Power Supply Recommendations

The OPAx992-Q1 is specified for operation from 2.7 V to 40 V (±1.35 V to ±20 V); many specifications apply from –40°C to 125°C or with specific supply voltages and test conditions.

**CAUTION**

Supply voltages larger than 40 V can permanently damage the device; see Section 6.1.

Place 0.1-µF 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, refer to Section 8.4.
8.4 Layout

8.4.1 Layout Guidelines

For best operational performance of the device, use good PCB layout practices, including:

- Noise can propagate into analog circuitry through the power pins of the circuit as a whole and op amp itself. Bypass capacitors are used to reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1-µF 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 circuitry is one of the simplest and most-effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Make sure to physically separate digital and analog grounds paying attention to the flow of the ground current.
- To reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If these traces cannot be kept separate, crossing the sensitive trace perpendicular is much better as opposed to in parallel with the noisy trace.
- Place the external components as close to the device as possible. As shown in Figure 8-4, keeping RF and RG close to the inverting input minimizes parasitic capacitance.
- Keep the length of input traces as short as possible. Always 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.
- Cleaning the PCB following board assembly is recommended for best performance.
- Any precision integrated circuit can experience performance shifts due to moisture ingress into the plastic package. Following any aqueous PCB cleaning process, baking the PCB assembly is recommended to remove moisture introduced into the device packaging during the cleaning process. A low temperature, post cleaning bake at 85°C for 30 minutes is sufficient for most circumstances.

8.4.2 Layout Example

Figure 8-3. Schematic for Noninverting Configuration Layout Example
Figure 8-4. Operational Amplifier Board Layout for Noninverting Configuration - SC70 (DCK) Package
9 Device and Documentation Support

9.1 Device Support

9.1.1 Development Support

9.1.1.1 TINA-TI™ (Free Software Download)

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

Available as a free download from the Analog eLab Design Center, TINA-TI offers extensive post-processing capability that allows users to format results in a variety of ways. Virtual instruments offer the ability to select input waveforms and probe circuit nodes, voltages, and waveforms, creating a dynamic quick-start tool.

Note

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

9.2 Documentation Support

9.2.1 Related Documentation

• Texas Instruments, MUX-Friendly, Precision Operational Amplifiers application brief
• Texas Instruments, EMI Rejection Ratio of Operational Amplifiers application report
• Texas Instruments, Op Amps With Complementary-Pair Input Stages application note
• Texas Instruments, 0-1-A, Single-Supply, Low-Side, Current Sensing Solution reference design (TIPD129)

9.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on Subscribe to updates 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.

9.4 Support Resources

TI E2E™ support forums are an engineer’s go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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9.6 Electrostatic Discharge Caution

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

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

9.7 Glossary

TI Glossary This glossary lists and explains terms, acronyms, and definitions.
10 Mechanical, Packaging, and Orderable Information

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

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<th>Orderable Device</th>
<th>Status (1)</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Eco Plan (2)</th>
<th>Lead finish/Ball material (6)</th>
<th>MSL Peak Temp (3)</th>
<th>Op Temp (°C)</th>
<th>Device Marking (4/5)</th>
<th>Samples</th>
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(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 JEDEC 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.
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OTHER QUALIFIED VERSIONS OF OPA2992-Q1, OPA4992-Q1, OPA992-Q1:
- Catalog: OPA2992, OPA4992, OPA992

NOTE: Qualified Version Definitions:
- Catalog - TI's standard catalog product
**TAPE AND REEL INFORMATION**

### REEL DIMENSIONS

- **Reel Diameter**
- **Reel Width (W1)**

### TAPE DIMENSIONS

- **A0**: Dimension designed to accommodate the component width
- **B0**: Dimension designed to accommodate the component length
- **K0**: Dimension designed to accommodate the component thickness
- **W**: Overall width of the carrier tape
- **P1**: Pitch between successive cavity centers

### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

- **Pocket Quadrants**
- **Sprocket Holes**
- **User Direction of Feed**

*All dimensions are nominal

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### TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal*

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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.
4. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25 mm per side.
5. Support pin may differ or may not be present.
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.
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.
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.
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.
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.
NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
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 0.15 each side.
  △ Body width does not include interlead flash. Interlead flash shall not exceed 0.25 each side.
E. Falls within JEDEC MO-153
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.
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.
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
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.
DGK (S-PDSO-G8)  PLASTIC SMALL-OUTLINE PACKAGE

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
E. Falls within JEDEC MO-187 variation AA, except interlead flash.

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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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