**OPAx376-Q1 Low-Noise, Low Quiescent Current, Precision e-trim™ Operational Amplifiers**

**1 Features**
- AEC-Q100 qualified for automotive applications:
  - Temperature grade 1: –40°C to +125°C, TA
- Functional-Safety Capable
  - Documentation available to aid functional safety system design (OPA376-Q1 and OPA2376-Q1)
- Low noise: 7.5 nV/√Hz at 1 kHz
- 0.1-Hz to 10-Hz noise: 0.8 μV p-p
- Quiescent current: 760 μA (typical)
- Low offset voltage: 5 μV (typical)
- Gain bandwidth product: 5.5 MHz
- Rail-to-rail input and output
- Single-supply operation
- Supply voltage: 2.2 V to 5.5 V
- Space-saving packages:
  - SC70, SOT-23, VSSOP, TSSOP

**2 Applications**
- Onboard (OBC) and wireless charger
- Inverter and motor control
- DC/DC converter
- Battery management system (BMS)

**3 Description**

The OPAx376-Q1 family represents a new generation of low-noise e-trim™ operational amplifiers, offering outstanding dc precision and ac performance. Rail-to-rail output, low offset (25 μV maximum), low noise (7.5 nV/√Hz), quiescent current of 950 μA (maximum), and a 5.5-MHz bandwidth make this device very attractive for a variety of precision and portable applications. In addition, this device has a reasonably wide supply range with excellent PSRR, making the OPA376-Q1 an excellent choice for applications that run directly from batteries without regulation.

The OPA376-Q1 (single version) is available in MicroSIZE SC70-5, SOT23-5, and SOIC-8 packages. The OPA2376-Q1 (dual) is offered in the SOIC-8 and VSSOP-8 package. The OPA4376-Q1 (quad) is offered in a TSSOP-14 package. All versions are specified for operation from –40°C to +125°C.

**Device Information**

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE(1)</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPA376-Q1</td>
<td>SC70 (5)</td>
<td>2.00 mm × 1.25 mm</td>
</tr>
<tr>
<td></td>
<td>SOT-23 (5)</td>
<td>2.90 mm × 1.60 mm</td>
</tr>
<tr>
<td></td>
<td>SOIC (8)</td>
<td>4.90 mm × 3.91 mm</td>
</tr>
<tr>
<td>OPA2376-Q1</td>
<td>SOIC (8)</td>
<td>4.90 mm × 3.91 mm</td>
</tr>
<tr>
<td></td>
<td>VSSOP (8)</td>
<td>3.00 mm × 3.00 mm</td>
</tr>
<tr>
<td>OPA4376-Q1</td>
<td>TSSOP (14)</td>
<td>5.00 mm × 4.40 mm</td>
</tr>
</tbody>
</table>

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

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**Input Voltage Noise Spectral Density**

**Offset Voltage Production Distribution**
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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 B (May 2016) to Revision C (March 2021) Page
• Updated the numbering format for tables, figures, and cross-references throughout the document........1
• Deleted HBM and CDM classification levels from Features and moved to ESD Ratings ....................1
• Added functional safety links to Features .........................................................................................1
• Changed Applications bullets...........................................................................................................1
• Changed ESD Ratings to show HBM and CDM classification levels.............................................6
• Added Figure 6-8, Common-Mode Voltage vs Temperature .........................................................9
• Added Figure 6-9, Offset Voltage vs Common-Mode Voltage .......................................................9

Changes from Revision A (January 2016) to Revision B (May 2016) Page
• Updated Applications examples.................................................................................................1
• Updated the Pin Functions Table for OPA4376-Q1.....................................................................3
• Updated HBM ESD Rating .......................................................................................................6
• Changed units on Channel Separation ....................................................................................8
• Deleted the temperature range parameters from the Electrical Characteristics table.................8
• Removed section regarding WCSP photosensitivity ..................................................................21

Changes from Revision * (April 2011) to Revision A (January 2016) Page
• Added Pin Functions table, ESD Ratings table, Recommended Operating Conditions table, Thermal Information tables, Feature Description section, Device Functional Modes, Application and Implementation section, Power Supply Recommendations section, Layout section, Device and Documentation Support section, and Mechanical, Packaging, and Orderable Information section.........................................................1
• Released the OPA2376-Q1 device as Production Data ..................................................................1
• Added the Input Offset Voltage and Input Offset Voltage Drift section to the Feature Description ....13

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Product Folder Links: OPA376-Q1 OPA2376-Q1 OPA4376-Q1
5 Pin Configuration and Functions

![Figure 5-1. OPA376-Q1: DBV (5-Pin SOT-23) Package, Top View](image)

![Figure 5-2. OPA376-Q1: DCK (5-Pin SC70) Package, Top View](image)

![Figure 5-3. OPA376-Q1: D (8-Pin SOIC) Package, Top View](image)

(1) NC denotes no internal connection.

**Table 5-1. Pin Functions: OPA376-Q1**

<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>+IN</td>
<td>3</td>
<td>Noninverting input*</td>
</tr>
<tr>
<td>-IN</td>
<td>4</td>
<td>Inverting input*</td>
</tr>
<tr>
<td>NC</td>
<td>1, 5, 8</td>
<td>No internal connection</td>
</tr>
<tr>
<td>OUT</td>
<td>6</td>
<td>Output</td>
</tr>
<tr>
<td>V+</td>
<td>7</td>
<td>Positive (highest) power supply*</td>
</tr>
<tr>
<td>V-</td>
<td>4</td>
<td>Negative (lowest) power supply*</td>
</tr>
</tbody>
</table>

*Refers to the respective power supply voltage.
Figure 5-4. OPA2376-Q1: D (8-Pin SOIC) and DGK (8-Pin VSSOP) Packages, Top View

Table 5-2. Pin Functions: OPA2376-Q1

<table>
<thead>
<tr>
<th>PIN NAME</th>
<th>NO.</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>+IN A</td>
<td>3</td>
<td>I</td>
<td>Noninverting input, channel A⁺</td>
</tr>
<tr>
<td>–IN A</td>
<td>2</td>
<td>I</td>
<td>Inverting input, channel A⁻</td>
</tr>
<tr>
<td>+IN B</td>
<td>5</td>
<td>I</td>
<td>Noninverting input, channel B⁺</td>
</tr>
<tr>
<td>–IN B</td>
<td>6</td>
<td>I</td>
<td>Inverting input, channel B⁻</td>
</tr>
<tr>
<td>OUT A</td>
<td>1</td>
<td>O</td>
<td>Output, channel A</td>
</tr>
<tr>
<td>OUT B</td>
<td>7</td>
<td>O</td>
<td>Output, channel B</td>
</tr>
<tr>
<td>V⁻</td>
<td>4</td>
<td>—</td>
<td>Negative (lowest) power supply</td>
</tr>
<tr>
<td>V⁺</td>
<td>8</td>
<td>—</td>
<td>Positive (highest) power supply</td>
</tr>
</tbody>
</table>
Figure 5-5. OPA4376-Q1: PW (14-Pin TSSOP) Package, Top View

<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUT A</td>
<td>O</td>
<td>Output, channel A</td>
</tr>
<tr>
<td>OUT B</td>
<td>O</td>
<td>Output, channel B</td>
</tr>
<tr>
<td>OUT C</td>
<td>O</td>
<td>Output, channel C</td>
</tr>
<tr>
<td>OUT D</td>
<td>O</td>
<td>Output, channel D</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>

Table 5-3. Pin Functions: OPA4376-Q1

<table>
<thead>
<tr>
<th>NAME</th>
<th>NO.</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>+IN A</td>
<td>3</td>
<td>I</td>
<td>Noninverting input, channel A*</td>
</tr>
<tr>
<td>–IN A</td>
<td>2</td>
<td>I</td>
<td>Inverting input, channel A−</td>
</tr>
<tr>
<td>+IN B</td>
<td>5</td>
<td>I</td>
<td>Noninverting input, channel B*</td>
</tr>
<tr>
<td>–IN B</td>
<td>6</td>
<td>I</td>
<td>Inverting input, channel B−</td>
</tr>
<tr>
<td>+IN C</td>
<td>10</td>
<td>I</td>
<td>Noninverting input, channel C*</td>
</tr>
<tr>
<td>–IN C</td>
<td>9</td>
<td>I</td>
<td>Inverting input, channel C−</td>
</tr>
<tr>
<td>+IN D</td>
<td>12</td>
<td>I</td>
<td>Noninverting input, channel D*</td>
</tr>
<tr>
<td>–IN D</td>
<td>13</td>
<td>I</td>
<td>Inverting input, channel D−</td>
</tr>
</tbody>
</table>
6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

<table>
<thead>
<tr>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>7</td>
<td>V</td>
</tr>
<tr>
<td>(V–) – 0.5</td>
<td>(V+) + 0.5</td>
<td>V</td>
</tr>
<tr>
<td>–10</td>
<td>10</td>
<td>mA</td>
</tr>
<tr>
<td>–40</td>
<td>125</td>
<td>°C</td>
</tr>
<tr>
<td>150</td>
<td></td>
<td>°C</td>
</tr>
</tbody>
</table>

(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 terminals are diode-clamped to the power-supply rails. Input signals that can 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

<table>
<thead>
<tr>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>±4000</td>
<td>V</td>
</tr>
<tr>
<td>±1000</td>
<td>V</td>
</tr>
</tbody>
</table>

(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)

<table>
<thead>
<tr>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 (±1.1)</td>
<td>5.5 (±2.75)</td>
<td>V</td>
</tr>
<tr>
<td>–40</td>
<td>150</td>
<td>°C</td>
</tr>
</tbody>
</table>
### 6.4 Thermal Information: OPA376-Q1

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>OPA376-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DCK (SC70)</td>
<td>DBV (SOT-23)</td>
</tr>
<tr>
<td>$R_{\theta JA}$</td>
<td>267</td>
<td>273.8</td>
</tr>
<tr>
<td>$R_{\theta JC(top)}$</td>
<td>80.9</td>
<td>126.8</td>
</tr>
<tr>
<td>$R_{\theta JB}$</td>
<td>54.8</td>
<td>85.9</td>
</tr>
<tr>
<td>$\psi_{JT}$</td>
<td>1.2</td>
<td>10.9</td>
</tr>
<tr>
<td>$\psi_{JB}$</td>
<td>54.1</td>
<td>84.9</td>
</tr>
<tr>
<td>$R_{\theta JC(bot)}$</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

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

### 6.5 Thermal Information: OPA2376-Q1

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>OPA2376-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D (SOIC)</td>
<td>DGK (VSSOP)</td>
</tr>
<tr>
<td>$R_{\theta JA}$</td>
<td>111.1</td>
<td>171.2</td>
</tr>
<tr>
<td>$R_{\theta JC(top)}$</td>
<td>54.7</td>
<td>63.9</td>
</tr>
<tr>
<td>$R_{\theta JB}$</td>
<td>51.7</td>
<td>92.8</td>
</tr>
<tr>
<td>$\psi_{JT}$</td>
<td>10.5</td>
<td>9.2</td>
</tr>
<tr>
<td>$\psi_{JB}$</td>
<td>51.2</td>
<td>91.2</td>
</tr>
<tr>
<td>$R_{\theta JC(bot)}$</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

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

### 6.6 Thermal Information: OPA4376-Q1

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>OPA4376-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PW (TSSOP)</td>
<td></td>
</tr>
<tr>
<td>$R_{\theta JA}$</td>
<td>107.8</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{\theta JC(top)}$</td>
<td>29.6</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{\theta JB}$</td>
<td>52.6</td>
<td>°C/W</td>
</tr>
<tr>
<td>$\psi_{JT}$</td>
<td>1.5</td>
<td>°C/W</td>
</tr>
<tr>
<td>$\psi_{JB}$</td>
<td>51.6</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{\theta JC(bot)}$</td>
<td>n/a</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

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

at $T_A = 25^\circ$C, $R_L = 10 \, \text{kΩ}$ 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><strong>OFFSET VOLTAGE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{OS}$</td>
<td>Input offset voltage</td>
<td>5</td>
<td>25</td>
<td>$\mu$V</td>
<td></td>
</tr>
<tr>
<td>$dV_{OS}/dT$</td>
<td>Input offset voltage versus temperature</td>
<td>$T_A = -40^\circ$C to $+85^\circ$C</td>
<td>0.26</td>
<td>1</td>
<td>$\mu$V/°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to $+125^\circ$C</td>
<td>0.32</td>
<td>2</td>
<td>$\mu$V/°C</td>
</tr>
<tr>
<td><strong>PSRR</strong></td>
<td>Input offset voltage versus power supply</td>
<td>$V_S = 2.2 , \text{V to } 5.5 , \text{V}$, $V_{CM} &lt; (V+) - 1.3 , \text{V}$</td>
<td>$T_A = 25^\circ$C</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to $+125^\circ$C</td>
<td>5</td>
<td>$\mu$V/V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Channel separation, dc (dual, quad)</td>
<td></td>
<td></td>
<td>0.5</td>
<td>$\mu$V/V</td>
</tr>
<tr>
<td><strong>INPUT BIAS CURRENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_B$</td>
<td>Input bias current</td>
<td>$T_A = 25^\circ$C</td>
<td>0.2</td>
<td>10</td>
<td>pA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to $+125^\circ$C</td>
<td>See Section 6.8</td>
<td></td>
<td>pA</td>
</tr>
<tr>
<td>$I_{OS}$</td>
<td>Input offset current</td>
<td></td>
<td></td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td><strong>NOISE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input voltage noise</td>
<td>$f = 0.1 , \text{Hz to } 10 , \text{Hz}$</td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Input voltage noise density</td>
<td>$f = 1 , \text{kHz}$</td>
<td></td>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>Input current noise</td>
<td>$f = 1 , \text{kHz}$</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>INPUT VOLTAGE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{CM}$</td>
<td>Common-mode voltage</td>
<td>See Figure 6-8</td>
<td>$(V-) - 0.1 , \text{V}$</td>
<td>$(V+) + 0.1 , \text{V}$</td>
<td>V</td>
</tr>
<tr>
<td><strong>CMRR</strong></td>
<td>Common-mode rejection ratio</td>
<td>$(V-) &lt; V_{CM} &lt; (V+) - 1.3 , \text{V}$</td>
<td>76</td>
<td>90</td>
<td>dB</td>
</tr>
<tr>
<td><strong>INPUT CAPACITANCE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Differential</td>
<td></td>
<td></td>
<td>6.5</td>
<td>pF</td>
</tr>
<tr>
<td></td>
<td>Common-mode</td>
<td></td>
<td></td>
<td>13</td>
<td>pF</td>
</tr>
<tr>
<td><strong>OPEN-LOOP GAIN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_{OL}$</td>
<td>Open-loop voltage gain</td>
<td>$50 , \text{mV} &lt; V_O &lt; (V+) - 50 , \text{mV}$, $R_L = 10 , \text{kΩ}$</td>
<td></td>
<td>120</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$100 , \text{mV} &lt; V_O &lt; (V+) - 100 , \text{mV}$, $R_L = 2 , \text{kΩ}$</td>
<td></td>
<td>120</td>
<td>126</td>
</tr>
<tr>
<td><strong>FREQUENCY RESPONSE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$GBW$</td>
<td>Gain-bandwidth product</td>
<td>$C_L = 100 , \text{pF}$, $V_S = 5.5 , \text{V}$</td>
<td>5.5</td>
<td>MHz</td>
<td></td>
</tr>
<tr>
<td>$SR$</td>
<td>Slew rate</td>
<td>$G = 1$, $C_L = 100 , \text{pF}$, $V_S = 5.5 , \text{V}$</td>
<td>2</td>
<td>V/μs</td>
<td></td>
</tr>
<tr>
<td>$t_s$</td>
<td>Settling time</td>
<td>0.1%, 2-V Step, $G = 1$, $C_L = 100 , \text{pF}$, $V_S = 5.5 , \text{V}$</td>
<td>1.6</td>
<td>μs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.01%, 2-V Step, $G = 1$, $C_L = 100 , \text{pF}$, $V_S = 5.5 , \text{V}$</td>
<td>2</td>
<td>μs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overload recovery time</td>
<td>$V_{IN} \times \text{Gain} &gt; V_S$</td>
<td>0.33</td>
<td>μs</td>
<td></td>
</tr>
<tr>
<td><strong>THD+N</strong></td>
<td>THD + noise</td>
<td>$V_O = 1 , \text{V RMS}$, $G = 1$, $f = 1 , \text{kHz}$, $R_L = 10 , \text{kΩ}$</td>
<td></td>
<td>0.00027%</td>
<td></td>
</tr>
<tr>
<td><strong>OUTPUT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voltage output swing from rail</td>
<td>$R_L = 10 , \text{kΩ}$</td>
<td>$T_A = 25^\circ$C</td>
<td>10</td>
<td>20</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to $+125^\circ$C</td>
<td>40</td>
<td>mV</td>
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<tr>
<td></td>
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<td>$T_A = 25^\circ$C</td>
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<td>50</td>
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<td></td>
<td></td>
<td>$T_A = -40^\circ$C to $+125^\circ$C</td>
<td>80</td>
<td>mV</td>
<td></td>
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<tr>
<td>$I_{SC}$</td>
<td>Short-circuit current</td>
<td></td>
<td></td>
<td>30 / –50</td>
<td>mA</td>
</tr>
<tr>
<td>$C_{LOAD}$</td>
<td>Capacitive load drive</td>
<td></td>
<td>See Section 6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_O$</td>
<td>Open-loop output impedance</td>
<td></td>
<td></td>
<td>150</td>
<td>Ω</td>
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<tr>
<td><strong>POWER SUPPLY</strong></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>$V_S$</td>
<td>Specified voltage</td>
<td></td>
<td></td>
<td>2.2</td>
<td>5.5</td>
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<tr>
<td></td>
<td>Operating voltage</td>
<td></td>
<td></td>
<td>2 to 5.5</td>
<td>V</td>
</tr>
<tr>
<td>$I_O$</td>
<td>Quiescent current per amplifier</td>
<td>$I_O = 0$, $V_S = 5.5 , \text{V}$, $V_{CM} &lt; (V+) - 1.3 , \text{V}$</td>
<td>$T_A = 25^\circ$C</td>
<td>760</td>
<td>950</td>
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<td></td>
<td></td>
<td></td>
<td>$T_A = -40^\circ$C to $+125^\circ$C</td>
<td>1</td>
<td>mA</td>
</tr>
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</table>
6.8 Typical Characteristics

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

---

**Figure 6-1.** Open-Loop Gain and Phase vs Frequency

**Figure 6-2.** Power-Supply and Common-Mode Rejection Ratio vs Frequency

**Figure 6-3.** Open-Loop Gain and Power-Supply Rejection Ratio vs Temperature

**Figure 6-4.** 0.1-Hz to 10-Hz Input Voltage Noise

**Figure 6-5.** Input Voltage Noise Spectral Density

**Figure 6-6.** Total Harmonic Distortion + Noise vs Frequency
6.8 Typical Characteristics (continued)

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

![Figure 6-7. Common-Mode Rejection Ratio vs Temperature](image1)

![Figure 6-8. Common-Mode Voltage vs Temperature](image2)

$(V-) = 0$ V  $T_A = 125^\circ C$

![Figure 6-9. Offset Voltage vs Common-Mode Voltage](image3)

![Figure 6-10. Quiescent Current vs Temperature](image4)

![Figure 6-11. Quiescent and Short-Circuit Current vs Supply Voltage](image5)

![Figure 6-12. Short-Circuit Current vs Temperature](image6)
6.8 Typical Characteristics (continued)

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

![Input Bias Current vs Temperature](image1)

![Output Voltage vs Output Current](image2)

![Offset Voltage Production Distribution](image3)

![Offset Voltage Drift Production Distribution](image4)

![Maximum Output Voltage vs Frequency](image5)

![Small-Signal Overshoot vs Load Capacitance](image6)
6.8 Typical Characteristics (continued)

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

![Figure 6-19. Small-Signal Pulse Response](image1)

![Figure 6-20. Large-Signal Pulse Response](image2)

![Figure 6-21. Settling Time vs Closed-Loop Gain](image3)

![Figure 6-22. Channel Separation vs Frequency](image4)

![Figure 6-23. Open-Loop Output Resistance vs Frequency](image5)
7 Detailed Description

7.1 Overview

The OPAx376-Q1 family belongs to a new generation of low-noise e-trim operational amplifiers, giving customers outstanding dc precision and ac performance. Low noise, rail-to-rail input and output, low offset, and drawing a low quiescent current, make these devices an excellent choice for a variety of precision and portable applications. In addition, these devices have a wide supply range with excellent PSRR, making the OPAx376-Q1 a great option for applications that are battery powered without regulation.

7.2 Functional Block Diagram

![Functional Block Diagram](image_url)

7.3 Feature Description

The OPAx376-Q1 family of precision amplifiers offers excellent dc performance as well as excellent ac performance. Operating from a single power-supply the OPAx376-Q1 is capable of driving large capacitive loads, has a wide input common-mode voltage range, and is well-suited to drive the inputs of successive-approximation response (SAR) analog-to-digital converters (ADCs) as well as 24-bit and higher resolution converters. Including internal ESD protection, the OPAx376-Q1 family is offered in a variety of industry-standard packages, including a wafer chip-scale package for applications that require space savings.

7.3.1 Operating Voltage

The OPAx376-Q1 family of amplifiers operate over a power-supply range of 2.2 V to 5.5 V (±1.1 V to ±2.75 V). Many of the specifications apply from –40°C to +125°C. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in Section 6.8.

7.3.2 Input Offset Voltage and Input Offset Voltage Drift

The OPAx376-Q1 family of e-trim operational amplifiers is manufactured using TI's proprietary trim technology, a method of trimming internal device parameters during either wafer probing or final testing. Each amplifier is trimmed in production, thereby minimizing errors associated with input offset voltage and input offset voltage drift.

7.3.3 Capacitive Load and Stability

The OPAx376-Q1 series of amplifiers may be used in applications where driving a capacitive load is required. As with all op amps, there may be specific instances where the OPAx376-Q1 can become unstable, leading to oscillation. The particular op amp circuit configuration, layout, gain, and output loading are some of the factors to consider when establishing whether an amplifier is be stable in operation. An op amp in the unity-gain (1 V/V) buffer configuration and driving a capacitive load exhibits a greater tendency to be unstable than an amplifier 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.
The OPAx376 in a unity-gain configuration can directly drive up to 250 pF of pure capacitive load. Increasing the gain enhances the ability of the amplifier to drive greater capacitive loads; see the typical characteristic plot Figure 6-18, Small-Signal Overshoot vs Load Capacitance. In unity-gain configurations, capacitive load drive can be improved by inserting a small (10-Ω to 20-Ω) resistor, \( R_S \), in series with the output, as shown in Figure 7-1. This resistor significantly reduces ringing while maintaining dc performance for purely capacitive loads. However, if there is a resistive load in parallel with the capacitive load, a voltage divider is created, introducing a gain error at the output and slightly reducing the output swing. The error introduced is proportional to the ratio \( R_S / R_L \), and is generally negligible at low output current levels.

![Figure 7-1. Improving Capacitive Load Drive](image)

### 7.3.4 Common-Mode Voltage Range

The input common-mode voltage range of the OPAx376-Q1 series extends 100 mV beyond the supply rails. The offset voltage of the amplifier is very low, from approximately (V–) to (V+) – 1 V, as shown in Figure 7-2. The offset voltage increases as common-mode voltage exceeds (V+) – 1 V. Common-mode rejection is specified from (V–) to (V+) – 1.3 V.

![Figure 7-2. Offset and Common-Mode Voltage](image)
7.3.5 Input and ESD Protection

The OPAx376-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. These ESD protection diodes also provide in-circuit, input overdrive protection, as long as the current is limited to 10 mA as stated in Section 6.1.

Figure 7-3 shows how a series input resistor may be added to the driven input to limit the input current. The added resistor contributes thermal noise at the amplifier input and its value must be kept to a minimum in noise-sensitive applications.

Figure 7-3. Input Current Protection

7.4 Device Functional Modes

The OPAx376-Q1 has a single functional mode and is operational when the power-supply voltage is greater than 2.2 V (±1.1 V). The maximum power supply voltage for the OPAx376-Q1 is 5.5 V (±2.75 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 OPAx376-Q1 family of e-trim operational amplifiers is built using a proprietary technique in which offset voltage is adjusted during the final steps of manufacturing. This technique compensates for performance shifts that can occur during the molding process. Through e-trim operational amplifier technology, the OPAx376-Q1 family delivers excellent offset voltage (5 μV, typical). Additionally, the amplifier boasts a fast slew rate, low drift, low noise, and excellent PSRR and $A_{OL}$. These 5.5-MHz CMOS op amps operate on 760 μA (typical) quiescent current.

8.1.1 Basic Amplifier Configurations

The OPAx376-Q1 family is unity-gain stable. It does not exhibit output phase inversion when the input is overdriven. A typical single-supply connection is shown in Figure 8-1. The OPA376-Q1 is configured as a basic inverting amplifier with a gain of –10 V/V. This single-supply connection has an output centered on the common-mode voltage, $V_{CM}$. For the circuit shown in Figure 8-1, this voltage is 2.5 V, but may be any value within the common-mode input voltage range.

![Figure 8-1. Basic Single-Supply Connection](attachment:image.png)
8.1.2 Active Filtering

The OPA376-Q1 series is well-suited for filter applications requiring a wide bandwidth, fast slew rate, low-noise, single-supply operational amplifier. Figure 8-2 shows a 50-kHz, second-order, low-pass filter. The components have been selected to provide a maximally-flat Butterworth response. Beyond the cutoff frequency, roll-off is −40 dB/dec. The Butterworth response is ideal for applications requiring predictable gain characteristics such as the anti-aliasing filter used ahead of an ADC.

![Second-Order Butterworth, 50-kHz Low-Pass Filter](image)

**Figure 8-2. Second-Order Butterworth, 50-kHz Low-Pass Filter**

8.1.3 Driving an Analog-to-Digital Converter

The low noise and wide gain bandwidth of the OPA376-Q1 family make it an ideal driver for ADCs. Figure 8-3 illustrates the OPA376-Q1 driving an ADS8327, 16-bit, 250-kSPS converter. The amplifier is connected as a unity-gain, noninverting buffer.

![Driving an ADS8327](image)

(1) Suggested value; may require adjustment based on specific application.

**Figure 8-3. Driving an ADS8327**
8.1.4 Phantom-Powered Microphone

The circuit shown in Figure 8-4 depicts how a remote microphone amplifier can be powered by a phantom source on the output side of the signal cable. The cable serves double duty, carrying both the differential output signal from and dc power to the microphone amplifier stage.

An OPA2376-Q1 serves as a single-ended input to a differential output amplifier with a 6-dB gain. Common-mode bias for the two op amps is provided by the dc voltage developed across the electret microphone element. A 48-V phantom supply is reduced to 5.1 V by the series 6.8-kΩ resistors on the output side of the cable, and the 4.7-kΩ resistors and zener diode on the input side of the cable. AC coupling blocks the different dc voltage levels from each other on each end of the cable.

An INA163 instrumentation amplifier provides differential inputs and receives the balanced audio signals from the cable.

The INA163 gain may be set from 0 dB to 80 dB by selecting the $R_G$ value. The INA163 circuit is typical of the input circuitry used in mixing consoles.

Figure 8-4. Phantom-Powered Electret Microphone
8.1.5 Speech Bandpass-Filtered Data Acquisition System

Figure 8-5 illustrates the OPA2376-Q1 driving a speech bandpass-filtered data acquisition system.

![Diagram of OPA2376-Q1 as a Speech Bandpass-Filtered Data Acquisition System]

(1) Electret microphone powered by $R_1$.

**Figure 8-5. OPA2376-Q1 as a Speech Bandpass-Filtered Data Acquisition System**

8.2 Typical Application

Low-pass filters are commonly employed in signal processing applications to reduce noise and prevent aliasing. The OPA376-Q1 is ideally suited to construct high-speed, high-precision active filters. Figure 8-6 shows a second-order, low-pass filter commonly encountered in signal processing applications.

![Diagram of Typical Application Schematic]

**Figure 8-6. Typical Application Schematic**
8.2.1 Design Requirements

Use the following parameters for this design example:

- Gain = 5 V/V (inverting gain)
- Low-pass cutoff frequency = 25 kHz
- Second-order Chebyshev filter response with 3-dB gain peaking in the passband

8.2.2 Detailed Design Procedure

The infinite-gain multiple-feedback circuit for a low-pass network function is shown in Figure 8-6. Use Equation 1 to calculate the voltage transfer function.

\[
\frac{\text{Output}(s)}{\text{Input}(s)} = \frac{-1/R_1 R_3 C_2 C_5}{s^2 + (s/C_2)(1/R_1 + 1/R_3 + 1/R_4) + 1/R_3 R_4 C_2 C_5}
\]  

(1)

This circuit produces a signal inversion. For this circuit, the gain at dc and the low-pass cutoff frequency are calculated by Equation 2:

\[
\text{Gain} = \frac{R_4}{R_1}
\]

\[
f_C = \frac{1}{2\pi} \sqrt{1/R_3 R_4 C_2 C_5}
\]  

(2)

Software tools are readily available to simplify filter design. WEBENCH® Filter Designer is a simple, powerful, and easy-to-use active filter design program. The WEBENCH Filter Designer lets you create optimized filter designs using a selection of TI operational amplifiers and passive components from TI's vendor partners.

Available as a web-based tool from the WEBENCH® Design Center, WEBENCH® Filter Designer allows you to design, optimize, and simulate complete multi-stage active filter solutions within minutes.

8.2.3 Application Curve

![Figure 8-7. Low-Pass Filter Transfer Function](image)

9 Power Supply Recommendations

The OPAx376-Q1 family of devices is specified for operation from 2.2 V to 5.5 V (±1.1 V to ±2.75 V); many specifications apply from −40°C to +125°C. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in Section 6.8.
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 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. For more detailed information refer to the Circuit Board Layout Techniques application report.
- In order 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 10-1, 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 may 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.

10.2 Layout Example

![Schematic Representation]

Figure 10-1. Layout Example
11 Device and Documentation Support

11.1 Device Support

11.1.1 Development Support

11.1.1.1 TINA-TI™ Simulation Software (Free Download)

TINA™ is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI™ simulation software 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 simulation software 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 simulation software 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.

11.1.1.2 TI Precision Designs


11.1.1.3 WEBENCH® Filter Designer

WEBENCH® Filter Designer is a simple, powerful, and easy-to-use active filter design program. The WEBENCH® Filter Designer lets you create optimized filter designs using a selection of TI operational amplifiers and passive components from TI's vendor partners.

Available as a web-based tool from the WEBENCH® Design Center, WEBENCH® Filter Designer allows you to design, optimize, and simulate complete multistage active filter solutions within minutes.

11.2 Documentation Support

11.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, [INA163 Low-Noise, Low-Distortion Instrumentation Amplifier](https://www.ti.com/lit/ds/symlink/ina163.pdf) data sheet
- Texas Instruments, [Shelf-Life Evaluation of Lead-Free Component Finishes](https://www.ti.com/lit/ds/symlink/shelf-life.pdf)
- Texas Instruments, [Tuning in Amplifiers](https://www.ti.com/lit/ds/symlink/tuning-in-amplifiers.pdf)
- Texas Instruments, [Using Infinite-Gain, MFB Filter Topology in Fully Differential Active Filters](https://www.ti.com/lit/ds/symlink/infinite-gain.pdf)

11.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](http://www.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.

11.4 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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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

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

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<th>Package Qty</th>
<th>Eco Plan (2)</th>
<th>Lead finish/Ball material (3)</th>
<th>MSL Peak Temp (3)</th>
<th>Op Temp (°C)</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 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.

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**OTHER QUALIFIED VERSIONS OF OPA2376-Q1, OPA376-Q1, OPA4376-Q1:**

- Catalog: OPA2376, OPA376, OPA4376

**NOTE:** Qualified Version Definitions:

- Catalog - TI's standard catalog product
### TAPE AND REEL INFORMATION

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0 (mm)</th>
<th>B0 (mm)</th>
<th>K0 (mm)</th>
<th>P1 (mm)</th>
<th>W (mm)</th>
<th>Pin1 Quadrant</th>
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*All dimensions are nominal.

**Definitions:**
- **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

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**TAPE DIMENSIONS**

- **K0**: Cavity depth
- **P1**: Pitch between successive cavity centers

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

- **Q1**
- **Q2**
- **Q3**
- **Q4**

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

- **Pocket Quadrants**
### TAPE AND REEL BOX DIMENSIONS

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<td>35.0</td>
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</tbody>
</table>

*All dimensions are nominal*
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.
NOTES: (continued)

5. Publication IPC-7351 may have alternate designs.
6. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
NOTES: (continued)

7. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
8. 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.

TEXAS INSTRUMENTS
www.ti.com
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:

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.
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.
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.
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