

Excellent Integrated System Limited

Stocking Distributor

Click to view price, real time Inventory, Delivery & Lifecycle Information:

[Texas Instruments](#)
[OPA548T](#)

For any questions, you can email us directly:

sales@integrated-circuit.com

OPA548 High-Voltage, High-Current Operational Amplifier

1 Features

- Wide Supply Range
 - Single Supply: 8 V to 60 V
 - Dual Supply: ± 4 V to ± 30 V
- High-Output Current:
 - 3-A Continuous
 - 5-A Peak
- Wide Output Voltage Swing
- Fully Protected:
 - Thermal Shutdown
 - Adjustable Current Limit
- Output Disable Control¹
- Thermal Shutdown Indicator
- High Slew Rate: 10 V
- Low Quiescent Current
- Packages:
 - 7-Lead TO-220, Zip and Straight Leads
 - 7-Lead DDPAK Surface-Mount

2 Applications

- Valve, Actuator Drivers
- SYNCHRO, SERVO Drivers
- Power Supplies
- Test Equipment
- Transducer Excitation
- Audio Amplifiers

3 Description

The OPA548 device is a low-cost, high-voltage and high-current operational amplifier that's ideal for driving a wide variety of loads. A laser-trimmed monolithic integrated circuit provides excellent low-level signal accuracy and high-output voltage and current.

The OPA548 device operates from either single or dual supplies for design flexibility. In single-supply operation, the input common-mode range extends below ground.

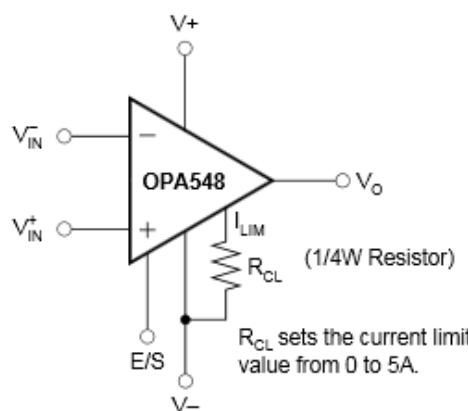
The OPA548 device is internally protected against over-temperature conditions and current overloads. In addition, the OPA548 device was designed to provide an accurate, user-selected current limit. Unlike other designs, which use a power resistor in series with the output current path, the OPA548 device senses the load indirectly. This allows the current limit to be adjusted from 0 A to 5 A with a resistor and potentiometer or controlled digitally with a voltage-out or current-out DAC.

Device Information⁽¹⁾

| PART NUMBER | PACKAGE | BODY SIZE (NOM) |
|-------------|------------|--------------------|
| OPA548 | TO-220 (7) | 10.17 mm x 8.38 mm |
| | TO-263 (7) | 10.10 mm x 8.89 mm |

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

Simplified Schematic



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. PRODUCTION DATA.

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com
Table of Contents

| | | | | | |
|----------|--|-----------|-----------|---|-----------|
| 1 | Features | 1 | 9.2 | Typical Applications | 14 |
| 2 | Applications | 1 | 9.3 | System Examples | 21 |
| 3 | Description | 1 | 10 | Power Supply Recommendations | 23 |
| 4 | Revision History | 2 | 10.1 | Output Stage Compensation | 23 |
| 5 | Description (continued) | 3 | 10.2 | Output Protection | 23 |
| 6 | Pin Configuration and Functions | 3 | 11 | Layout | 25 |
| 7 | Specifications | 5 | 11.1 | Layout Guidelines | 25 |
| | 7.1 Absolute Maximum Ratings | 5 | 11.2 | Layout Example | 26 |
| | 7.2 ESD Ratings | 5 | 11.3 | Power Dissipation | 26 |
| | 7.3 Recommended Operating Conditions | 5 | 11.4 | Thermal Considerations | 27 |
| | 7.4 Thermal Information | 5 | 11.5 | Heat Sinking | 28 |
| | 7.5 Electrical Characteristics | 6 | 12 | Device and Documentation Support | 30 |
| | 7.6 Typical Characteristics | 8 | 12.1 | Device Support | 30 |
| 8 | Detailed Description | 12 | 12.2 | Documentation Support | 30 |
| | 8.1 Overview | 12 | 12.3 | Community Resources | 30 |
| | 8.2 Functional Block Diagram | 12 | 12.4 | Trademarks | 30 |
| | 8.3 Feature Description | 12 | 12.5 | Electrostatic Discharge Caution | 30 |
| | 8.4 Device Functional Modes | 13 | 12.6 | Glossary | 30 |
| 9 | Application and Implementation | 14 | 13 | Mechanical, Packaging, and Orderable | 31 |
| | 9.1 Application Information | 14 | | Information | |

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Revision B (October 2003) to Revision C | Page |
|--|-------------|
| • Added <i>ESD Ratings</i> table, <i>Feature Description</i> section, <i>Device Functional Modes</i> , <i>Application and Implementation</i> section, <i>Power Supply Recommendations</i> section, <i>Layout</i> section, <i>Device and Documentation Support</i> section, and <i>Mechanical, Packaging, and Orderable Information</i> section | 1 |

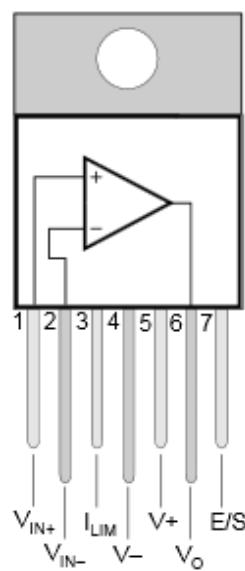
5 Description (continued)

The Enable/Status (E/S) pin provides two functions. An input on the pin not only disables the output stage to effectively disconnect the load, but also reduces the quiescent current to conserve power. The E/S pin output can be monitored to determine if the OPA548 is in thermal shutdown.

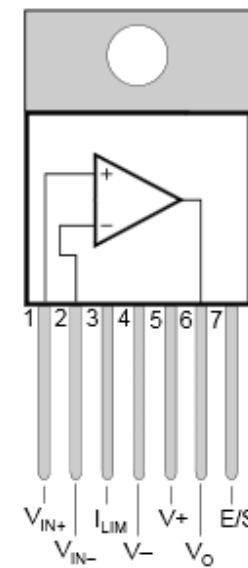
The OPA548 device is available in an industry-standard 7-lead staggered and straight lead TO-220 package, and a 7-lead DDPAK surface-mount plastic power package. The copper tab allows easy mounting to a heat sink or circuit board for excellent thermal performance. The device is specified for operation over the extended industrial temperature range, -40°C to 85°C . A SPICE macromodel is available for design analysis.

6 Pin Configuration and Functions

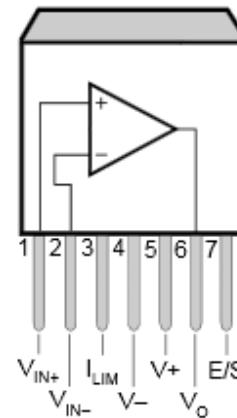
**KVT and KC Packages Stagger-Formed
7-Pin TO-220
Top View**



**KVT and KC Packages Straight-Formed
7-Pin TO-220
Top View**



**KTW Package Surface-Mount
7-Pin TO-263
Top View**



OPA548

SBOS070C –OCTOBER 1997–REVISED JUNE 2015

www.ti.com
Pin Functions

| PIN | | I/O | DESCRIPTION |
|-----------|-----|-----|--|
| NAME | NO. | | |
| V_{IN+} | 1 | I | Noninverting input |
| V_{IN-} | 2 | I | Inverting input |
| I_{LIM} | 3 | I | Current limit set |
| V_- | 4 | I | Negative power supply |
| V_+ | 5 | I | Positive power supply |
| V_O | 6 | O | Output |
| E/S | 7 | I/O | Enable/disable control input, thermal shutdown status output |

7 Specifications

7.1 Absolute Maximum Ratings

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

| | | MIN | MAX | UNIT |
|--------------------------------------|------------|---------------|-----|------|
| Output current | | See Figure 40 | | |
| Supply voltage, V+ to V- | | 60 | | V |
| Input voltage | (V-) -0.5V | (V+) + 0.5 | | V |
| Input shutdown voltage | | | | V+ |
| Operating temperature | -40 | 125 | | °C |
| Junction temperature | | 150 | | °C |
| T _{stg} Storage temperature | -55 | 125 | | °C |

(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.

7.2 ESD Ratings

| | | VALUE | UNIT |
|--|---|-------|------|
| V _(ESD) Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾ | ±2000 | V |
| | Machine model | ±200 | |

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

7.3 Recommended Operating Conditions

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

| | MIN | NOM | MAX | UNIT |
|------------------------|---------|-----|---------|------|
| Supply Voltage (V+-V-) | 8(+/-4) | | 60(±30) | V |
| Specified temperature | -40 | | 125 | °C |

7.4 Thermal Information

| THERMAL METRIC ⁽¹⁾ | OPA548 | | UNIT |
|--|---------------------|-------------|------|
| | KVT and KC (TO-220) | KTW (DDPAK) | |
| | 7 PINS | 7 PINS | |
| R _{θJA} Junction-to-ambient thermal resistance | 30.2 | 30.2 | °C/W |
| R _{θJC(top)} Junction-to-case (top) thermal resistance | 37.4 | 37.4 | °C/W |
| R _{θJB} Junction-to-board thermal resistance | 14.4 | 14.4 | °C/W |
| Ψ _{JT} Junction-to-top characterization parameter | 5.1 | 5.1 | °C/W |
| Ψ _{JB} Junction-to-board characterization parameter | 14.3 | 14.3 | °C/W |
| R _{θJC(bot)} Junction-to-case (bottom) thermal resistance | 0.2 | 0.2 | °C/W |

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

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

7.5 Electrical Characteristics

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

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--|--|------------------|--|----------------|-----------------------|
| OFFSET VOLTAGE | | | | | |
| Input Offset Voltage | $V_{CM} = 0$, $I_O = 0$ | | ± 2 | ± 10 | mV |
| vs Temperature | $T_A = -40^\circ C$ to $85^\circ C$ | | ± 30 | | $\mu V/^\circ C$ |
| vs Power supply | $V_{CM} = 0$ V | | 30 | 100 | $\mu V/V$ |
| INPUT BIAS CURRENT⁽¹⁾ | | | | | |
| Input Bias Current ⁽²⁾ | $V_{CM} = 0$ V | -100 | -500 | | nA |
| vs Temperature | $T_A = -40^\circ C$ to $85^\circ C$ | ± 0.5 | | | $nA/^\circ C$ |
| Input Offset Current | $V_{CM} = 0$ V | ± 5 | ± 50 | | nA |
| NOISE | | | | | |
| Input Voltage Noise Density, $f = 1$ kHz | | | 90 | | nV/\sqrt{Hz} |
| Current Noise Density, $f = 1$ kHz | | | 200 | | fA/\sqrt{Hz} |
| INPUT VOLTAGE RANGE | | | | | |
| Common-Mode Voltage Range: | Positive | Linear Operation | $(V+) - 3$ | $(V+) - 2.3$ | V |
| | Negative | Linear Operation | $(V-) - 0.1$ | $(V-) - 0.2$ | V |
| Common-Mode Rejection | $V_{CM} = (V-) - 0.1$ V to $(V+) - 3$ V | | 80 | 95 | dB |
| INPUT IMPEDANCE | | | | | |
| Differential | | | $10^7 \parallel 6$ | | $\Omega \parallel pF$ |
| Common-Mode | | | $10^9 \parallel 4$ | | $\Omega \parallel pF$ |
| OPEN-LOOP GAIN | | | | | |
| Open-Loop Voltage Gain | $V_O = \pm 25$ V, $R_L = 1$ k Ω | 90 | 98 | | dB |
| | $V_O = \pm 25$ V, $R_L = 8$ Ω | | 90 | | dB |
| FREQUENCY RESPONSE | | | | | |
| Gain-Bandwidth Product | $R_L = 8$ Ω | | 1 | | MHz |
| Slew Rate | $G = 1$, 50Vp-p, $R_L = 8$ Ω | | 10 | | V/ μ s |
| Full-Power Bandwidth | | | See <i>Typical Characteristics</i> | | kHz |
| Settling Time: $\pm 0.1\%$ | $G = -10$, 50-V Step | | 15 | | μ s |
| Total Harmonic Distortion + Noise, $f = 1$ kHz | $R_L = 8$ Ω , $G = 3$, Power = 10 W | | 0.02% ⁽³⁾ | | |
| OUTPUT | | | | | |
| Voltage Output | Positive | $I_O = 3$ A | $(V+) - 4.1$ | $(V+) - 3.7$ | V |
| | Negative | $I_O = -3$ A | $(V-) + 3.7$ | $(V-) + 3.3$ V | |
| | Positive | $I_O = 0.6$ A | $(V+) - 2.4$ | $(V+) - 2.1$ V | |
| | Negative | $I_O = -0.6$ A | $(V-) + 1.3$ | $(V-) + 1$ V | |
| Maximum continuous current output: | DC | ± 3 | | A | A |
| | AC | 3 | | Arms | Arms |
| Leakage Current, Output Disabled, DC | | | See <i>Typical Characteristics</i> | | |
| Output Current Limit | | | | | |
| Current Limit Range | | | 0 to ± 5 | | A |
| Current Limit Equation | | | $I_{LIM} = (15000)(4.75)/(13750 W + R_{CL})$ | | A |
| Current Limit Tolerance ⁽¹⁾ | $R_{CL} = 14.8$ kW ($I_{LIM} = \pm 2.5$ A), $R_L = 8$ Ω | | ± 100 | ± 250 | mA |
| Capacitive Load Drive | | | See Figure 19 | | |
| OUTPUT ENABLE /STATUS (E/S) PIN | | | | | |
| Shutdown Input Mode | | | | | |
| $V_{E/S}$ HIGH (output enabled) | E/S Pin Open or Forced High | $(V-) + 2.4$ | | | V |

(1) High-speed test at $T_J = 25^\circ C$.

(2) Positive conventional current flows into the input terminals.

(3) See Figure 12 for additional power levels.

Electrical Characteristics (continued)

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

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|------------------------------------|--|---------------|--------------|--------------|--------------|
| $V_{E/S}$ LOW (output disabled) | E/S Pin Forced Low | | | $(V-) + 0.8$ | V |
| $I_{E/S}$ HIGH (output enabled) | E/S Pin High | | | -65 | μA |
| $I_{E/S}$ LOW (output disabled) | E/S Pin Low | | | -70 | μA |
| Output Disable Time | | | | 1 | μs |
| Output Enable Time | | | | 3 | μs |
| Thermal Shutdown Status Output | | | | | |
| Normal Operation | Sourcing 20 μA | $(V-) + 2.4$ | $(V-) + 3.5$ | | V |
| Thermally Shutdown | Sinking 5 μA , $T_J > 160^\circ C$ | $(V-) + 0.35$ | $(V-) + 0.8$ | | V |
| Junction Temperature | Shutdown | | | 160 | $^\circ C$ |
| | Reset from Shutdown | | | 140 | $^\circ C$ |
| POWER SUPPLY | | | | | |
| Specified Voltage | | | ± 30 | | V |
| Operating Voltage Range | | ± 4 | | ± 30 | V |
| Quiescent Current | I_{LIM} Connected to V_- , $I_O = 0$ | | ± 17 | ± 20 | mA |
| Quiescent Current, Shutdown Mode | I_{LIM} Connected to V_- , $I_O = 0$ | | ± 6 | | nA |
| TEMPERATURE RANGE | | | | | |
| Specified Range | | -40 | | 85 | $^\circ C$ |
| Operating Range | | -40 | | 125 | $^\circ C$ |
| Storage Range | | -55 | | 125 | $^\circ C$ |
| Thermal Resistance, R_{\thetaJC} | | | | | |
| 7-Lead DDPAK, 7-Lead TO-220 | f > 50 Hz | | 2 | | $^\circ C/W$ |
| 7-Lead DDPAK, 7-Lead TO-220 | DC | | 2.5 | | $^\circ C/W$ |
| Thermal Resistance, R_{\thetaJA} | | | | | |
| 7-Lead DDPAK, 7-Lead TO-220 | No Heat Sink | | 65 | | $^\circ C/W$ |

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

7.6 Typical Characteristics

At $T_{CASE} = 25^\circ\text{C}$, $V_S = \pm 30\text{V}$ and E/S pin open, unless otherwise noted.

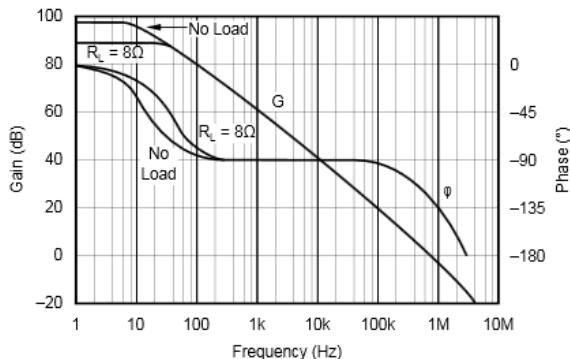


Figure 1. Open-Loop Gain and Phase vs Frequency

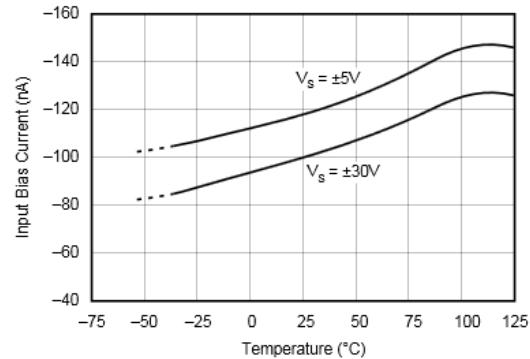


Figure 2. Input Bias Current vs Temperature

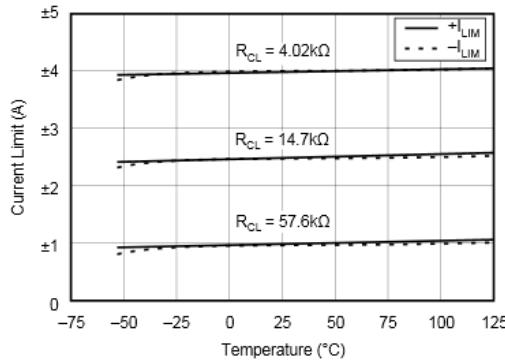


Figure 3. Current Limit vs Temperature

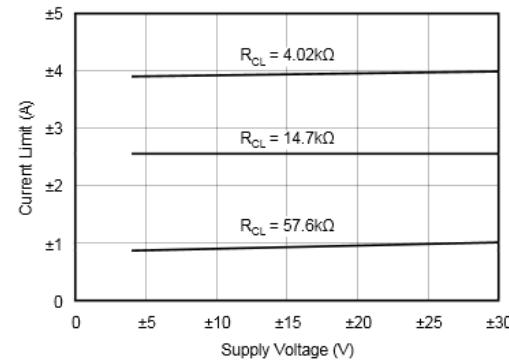


Figure 4. Current Limit vs Supply Voltage

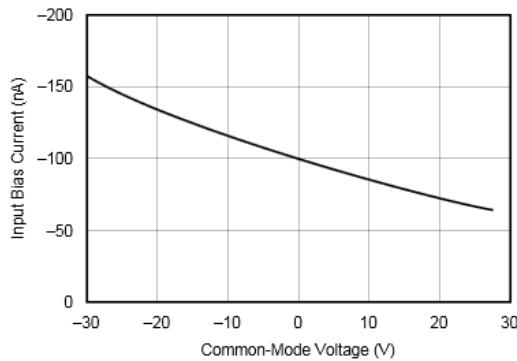


Figure 5. Input Bias Current vs Common-Mode Voltage

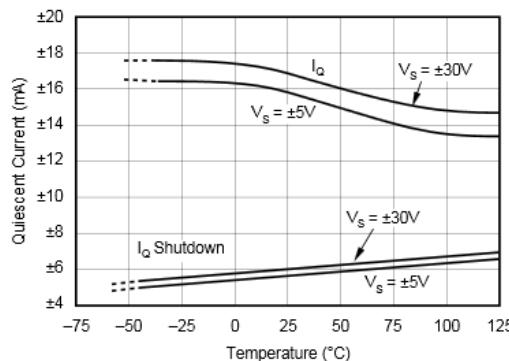
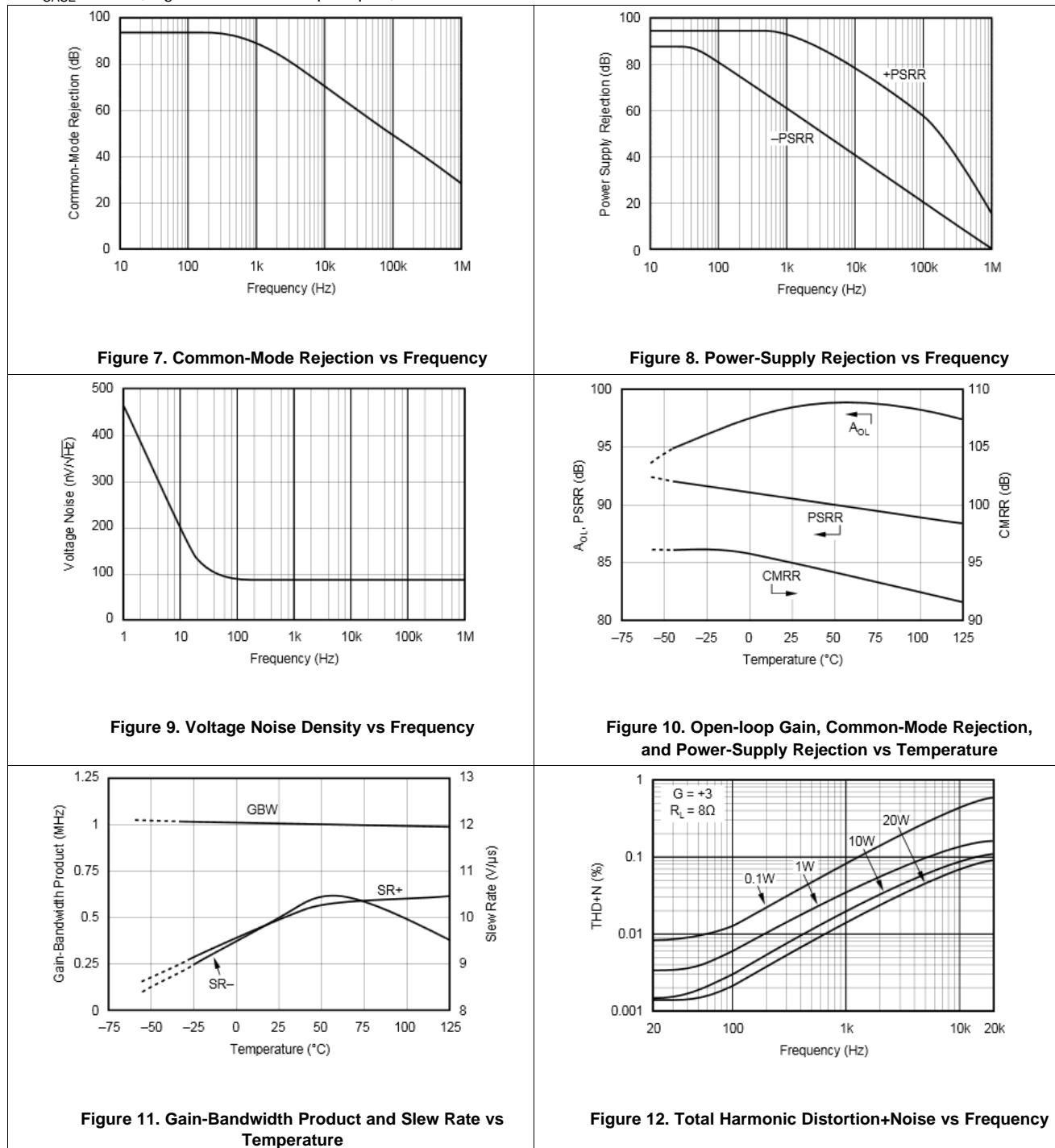


Figure 6. Quiescent Current vs Temperature

Typical Characteristics (continued)

At $T_{CASE} = 25^\circ\text{C}$, $V_S = \pm 30\text{V}$ and E/S pin open, unless otherwise noted.



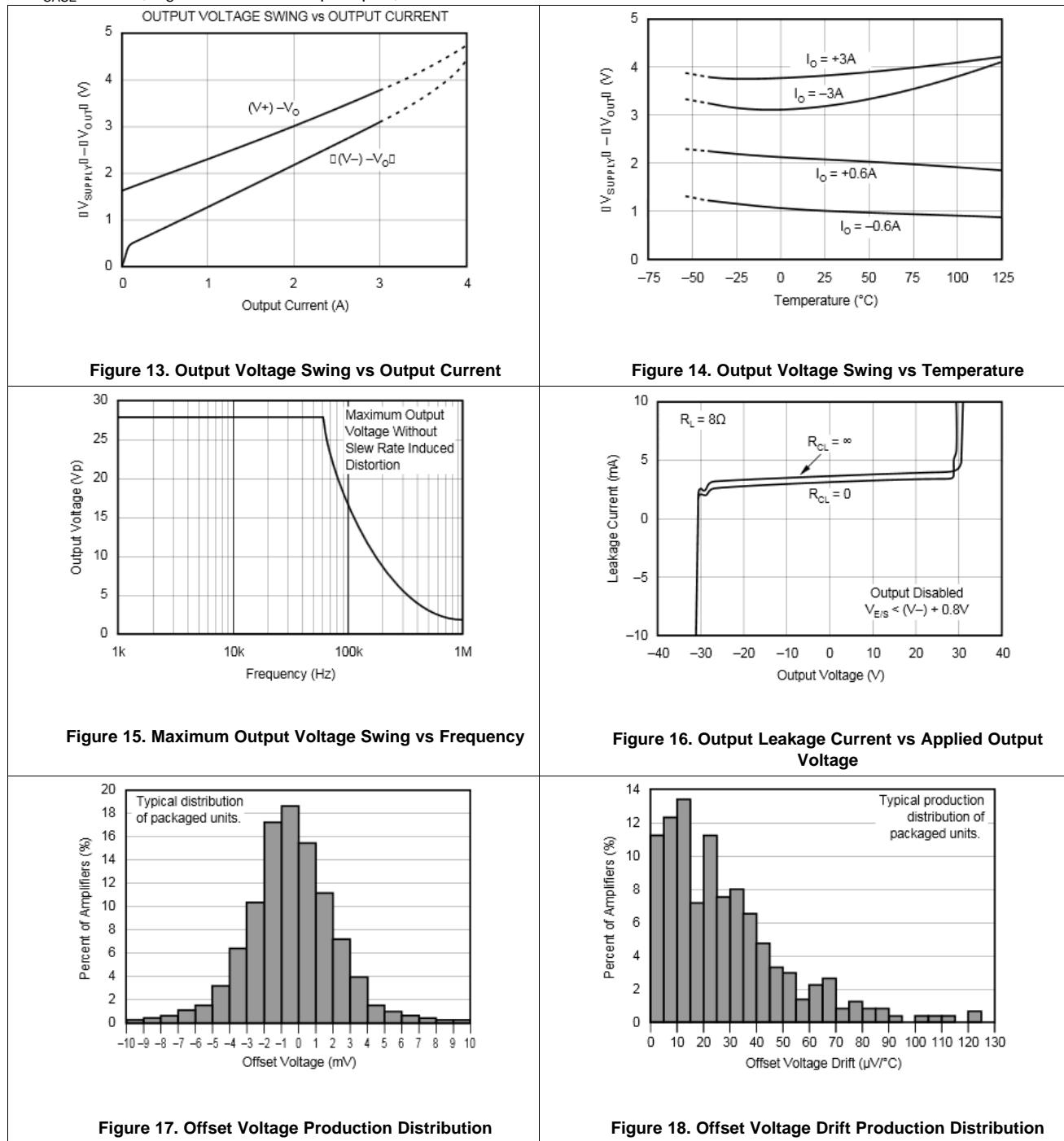
OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

Typical Characteristics (continued)

At $T_{CASE} = 25^\circ\text{C}$, $V_S = \pm 30\text{V}$ and E/S pin open, unless otherwise noted.



Typical Characteristics (continued)

At $T_{CASE} = 25^\circ\text{C}$, $V_S = \pm 30\text{V}$ and E/S pin open, unless otherwise noted.

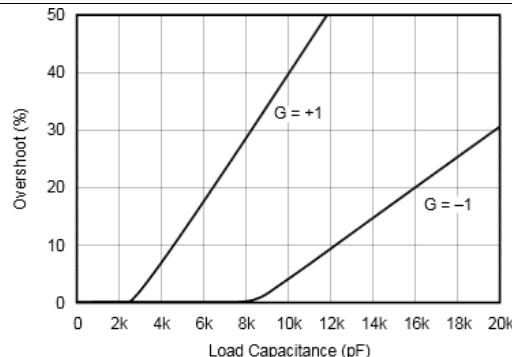


Figure 19. Small-Signal Overshoot vs Load Capacitance

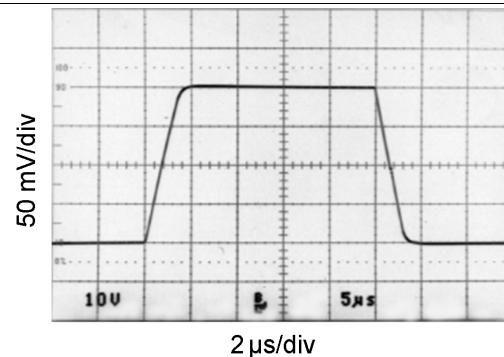


Figure 20. Large-Signal Step Response

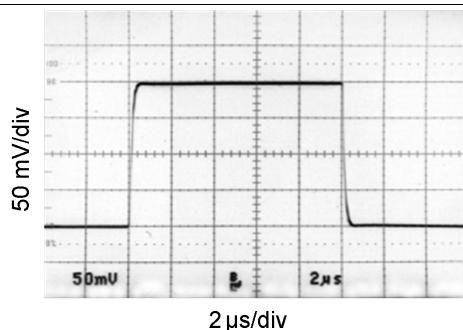


Figure 21. Small-Signal Step Response

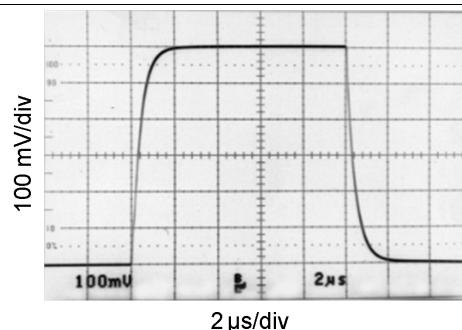


Figure 22. Small-Signal Step Response

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

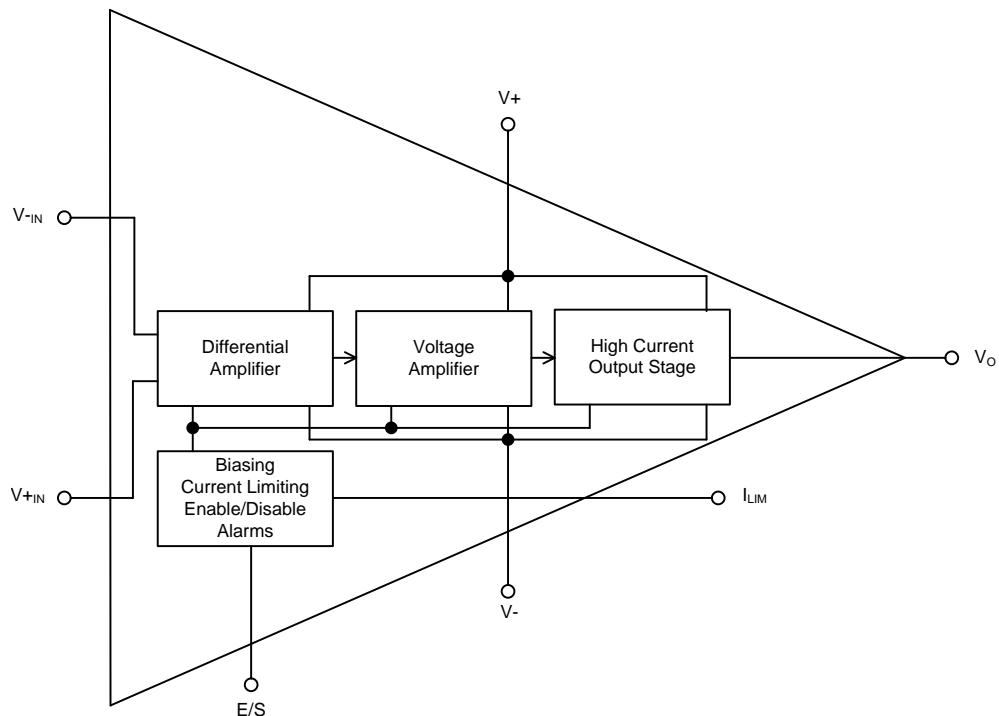
www.ti.com

8 Detailed Description

8.1 Overview

The OPA548 device uses a PNP input stage (resulting in negative bias currents at each input) without input bias current compensation so matched resistances on the inputs will reduce errors. After the main voltage gain stage is the high current output stage with temperature compensated class A/B biasing to reduce crossover distortion. Local feedback in the output stage may require additional compensation for highly reactive loads (see *Output Stage Compensation*).

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Adjustable Current Limit

The OPA548 features an accurate, user-selected current limit. The current limit is set from 0 A to 5 A by controlling the input to the I_{LIM} pin. Unlike other designs, which use a power resistor in series with the output current path, the OPA548 senses the load indirectly. This allows the current limit to be set with a 0- μ A to 330- μ A control signal. In contrast, other designs require a limiting resistor to handle the full output current (5 A in this case).

With the OPA548, the simplest method for adjusting the current limit uses a resistor or potentiometer connected between the I_{LIM} pin and V_- according to the [Equation 1](#):

$$R_{CL} = \frac{(15000)(4.75)}{I_{LIM}} - 13750 \Omega \quad (1)$$

The low-level control signal (0 μ A to 330 μ A) also allows the current limit to be digitally controlled.

See [Figure 41](#) for a simplified schematic of the internal circuitry used to set the current limit. Leaving the I_{LIM} pin open programs the output current to zero, while connecting I_{LIM} directly to V_- programs the maximum output current limit, typically 5 A.

Feature Description (continued)

8.3.2 Enable/Status (E/S) Pin

The Enable/Status pin provides two functions: forcing this pin LOW disables the output stage, or E/S can be monitored to determine if the OPA548 is in thermal shutdown. One or both of these functions can be used on the same device using single or dual supplies. For normal operation (output enabled), the E/S pin can be left open or pulled HIGH (at least 2.4 V more than the negative rail). A small value capacitor connected between the E/S pin and V₋ may be required for noisy applications.

8.3.3 Thermal Shutdown Status

Internal thermal shutdown circuitry shuts down the output when the die temperature reaches approximately 160°C, resetting when the die has cooled to 140°C. The E/S pin can be monitored to determine if shutdown has occurred. During normal operation the voltage on the E/S pin is typically 3.5 V more than the negative rail. Once shutdown has occurred, this voltage drops to approximately 350 mV more than the negative rail.

8.4 Device Functional Modes

8.4.1 Output Disable

A unique feature of the OPA548 is its output disable capability. This function not only conserves power during idle periods (quiescent current drops to approximately 6 mA), but also allows multiplexing in low frequency ($f < 20$ kHz), multichannel applications. Signals greater than 20 kHz may cause leakage current to increase in devices that are shutdown. [Figure 33](#) shows the two OPA548s in a switched amplifier configuration. The ON/OFF state of the two amplifiers is controlled by the voltage on the E/S pin.

To disable the output, the E/S pin is pulled LOW, no greater than 0.8 V more than the negative rail. Typically the output is shutdown in 1 μ s. [Figure 23](#) provides an example of how to implement this function using a single supply. [Figure 24](#) gives a circuit for dual-supply applications. To return the output to an enabled state, the E/S pin should be disconnected (open) or pulled to at least (V₋) + 2.4 V. It should be noted that pulling the E/S pin HIGH (output enabled) does not disable internal thermal shutdown.

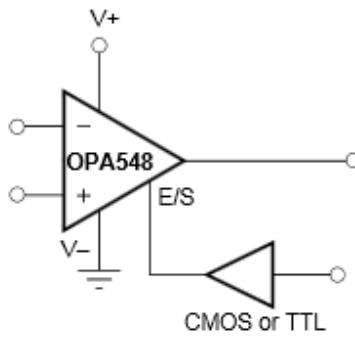
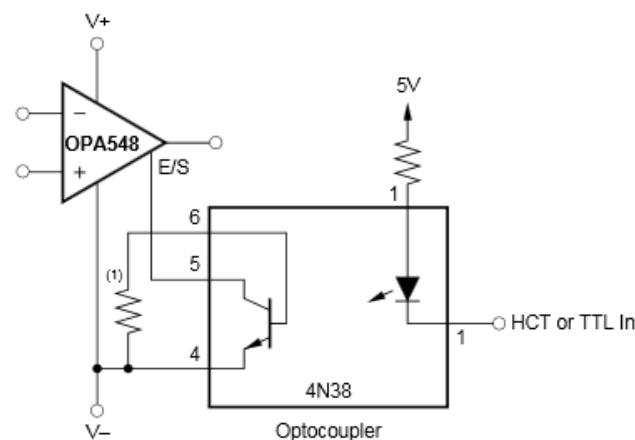


Figure 23. Output Disable With a Single Supply



NOTE: (1) Optional—may be required to limit leakage current of optocoupler at high temperatures.

Figure 24. Output Disable With Dual Supplies

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

9 Application and Implementation

NOTE

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

9.1 Application Information

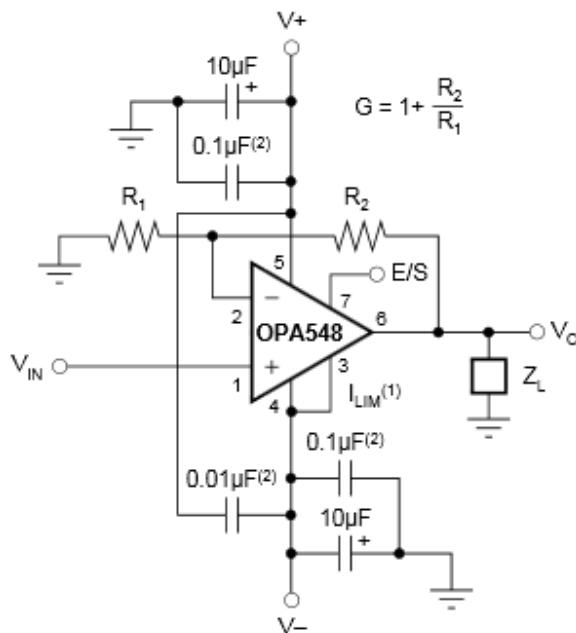
The OPA548 is specified for operation from 8 V to 60 V (± 4 V to ± 30 V). Specifications apply over the -40°C to 85°C temperature range while the device operates from -40°C to 125°C . Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in *Typical Characteristics*.

9.2 Typical Applications

9.2.1 Basic Circuit Connections

Figure 25 shows the OPA548 connected as a basic noninverting amplifier. The OPA548 can be used in virtually any operational amplifier configuration.

Power-supply terminals should be bypassed with low series impedance capacitors. The technique shown in Figure 45, using a ceramic and tantalum type in parallel is recommended. In addition, we recommend a 0.01- μF capacitor between V+ and V- as close to the OPA548 as possible. Power-supply wiring should have low series impedance.



NOTES: (1) I_{LIM} connected to V- gives the maximum current limit, 5A (peak). (2) Connect capacitors directly to package power-supply pins.

Figure 25. Basic Circuit Connections Example

Typical Applications (continued)

9.2.1.1 Design Requirements

To design an example of a noninverting circuit, the following requirements are spelled out:

- Gain: 1
- Output voltage swing: ± 10 V
- Maximum Output Current: ± 2.5 A
- Load: $4\text{-}\Omega$ resistive
- Ambient Temperature: Up to 40°C

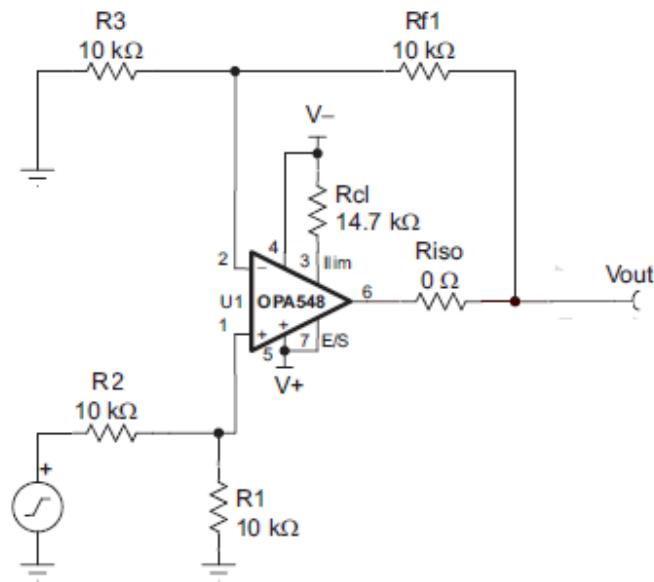


Figure 26. Noninverting Amplifier Configuration Schematic

9.2.1.2 Detailed Design Procedure

9.2.1.2.1 Power Supply Requirements

Select the power supply based on the requirement to achieve a ± 10 -V output with up to a 2.5-A load. The maximum value for output voltage swing at 3-A is approximately within 4 V of either rail, standard 15-V power supplies rated at >2.5 A each will suffice.

9.2.1.2.2 Gain Setting and Input Configuration

A unity gain noninverting application could be provided by simply connecting the output of an operational amplifier back to its input, with the signal applied to the noninverting input. Power operational amplifiers are frequently subject to unpredictable load impedances that can cause instability. Increasing gain can enhance stability. Furthermore, the feedback network provides locations for further opportunities for stability enhancing components if necessary.

In this application two 10-kΩ resistors are used for the input and feedback resistance, which would normally result in a noninverting gain of 2. Adding a voltage divider consisting of R1 and R2 reduces the input signal by half before it is applied to the operational amplifier. In this case the solution just happens to restore us back to the desired overall gain of 1. This solution using an identical pair of resistors before the noninverting input between the signal and ground creates what is known as a difference amplifier.

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

Typical Applications (continued)

9.2.1.2.3 Current Limit

The OPA548 provides means to limit the maximum output current delivered by the amplifier. A resistor between the negative supply and the amplifier's l_{lim} pin, or a DAC can be used to set the current limit. For this circuit a 14.7-k Ω resistor (R_{cl}) limits the output current to approximately 2.5 A.

9.2.1.2.4 Safe-Operating-Area

Plotting the load on the Safe-Operating-Area (SOA) curve allows the safety of the application to be assessed. Figure 40 depicts the 4- Ω load on the curve. With a resistive load, maximum dissipation occurs at an output voltage one-half of the supply voltage, in this case 7.5 V and 1.875 A for 22.5 W.

Consideration should be given to the condition of a shorted output. In this application this is a stress of 15 V at 2.5 A on the output stage, or 37.5 W which is just within the 50-W SOA of the OPA548. How long the circuit can withstand a short to ground will be determined by the size of the heatsink. Ultimately the thermal shutdown will activate providing short circuit protection, although even this is not recommended as a continuous condition.

9.2.1.2.5 Heat Sinking

From [Safe-Operating-Area](#) we know we will must support 22.5 W of dissipation up to the 40°C ambient requirements of the application. This indicates the need for a heatsink with a $R_{\theta HA} < 2.5^{\circ}\text{C}/\text{W}$, such as an Aavid Thermalloy 530002B02500G.

9.2.1.3 Application Curve

Figure 27 shows the expected results for the Noninverting Operation of the OPA548. The left picture shows the Noninverting Operation in dual supply mode and the right picture shows the Noninverting Operation in single supply mode. The input signal is a zero-centered sine wave with an amplitude of 10 V p-p and a frequency of 1 kHz. In this trace the OPA548 is delivering a peak current of 1.25 A to the 4- Ω load.

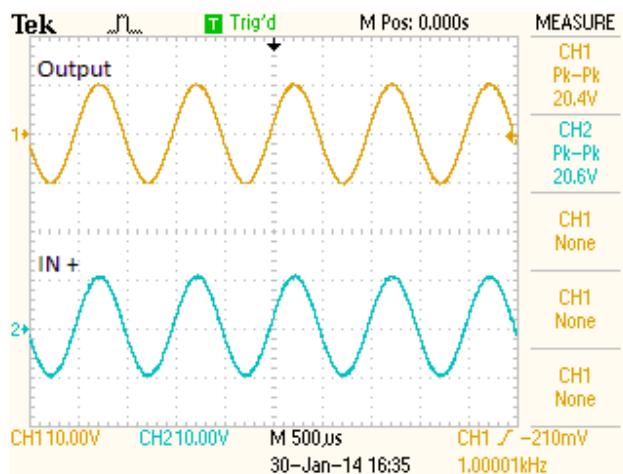


Figure 27. Noninverting Operation, Dual-Supply Waveforms

Typical Applications (continued)

9.2.2 Monitoring Single- and Dual-Supplies

Figure 28 gives an example of monitoring shutdown in a single-supply application. Figure 29 provides a circuit for dual supplies. External logic circuitry or an LED could be used to indicate if the output has been thermally shutdown, see Figure 31.

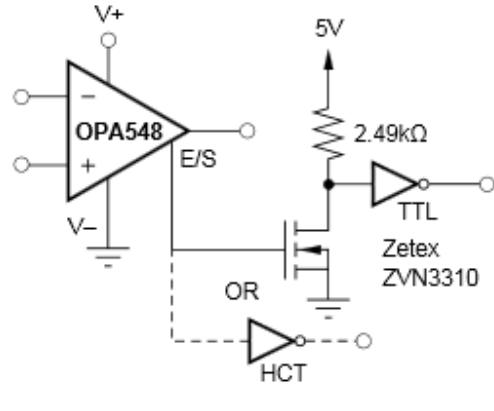


Figure 28. Thermal Shutdown Status With a Single-Supply

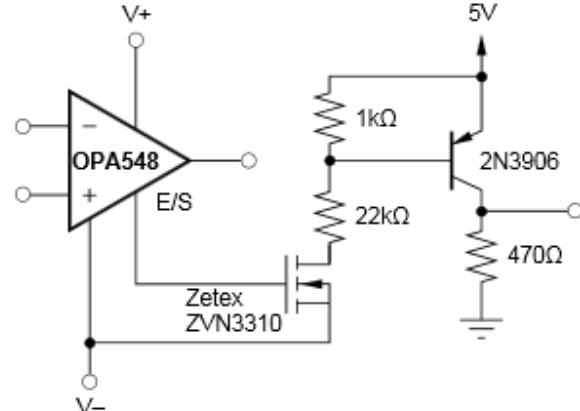


Figure 29. Thermal Shutdown Status With Dual-Supplies

9.2.2.1 Design Requirements

See the previous [Design Requirements](#).

9.2.2.2 Detailed Design Procedure

9.2.2.2.1 Output Disable and Thermal Shutdown Status

As mentioned earlier, the OPA548's output can be disabled and the disable status can be monitored simultaneously. Figure 28 and Figure 29 provide examples interfacing to the E/S pin while using a single supply and dual supplies, respectively.

OPA548

SBOS070C –OCTOBER 1997–REVISED JUNE 2015

www.ti.com

Typical Applications (continued)

9.2.3 Programmable Power Supply

A programmable source or sink power supply can easily be built using the OPA548. Both the output voltage and output current are user-controlled. See [Figure 30](#) for a circuit using potentiometers to adjust the output voltage and current while [Figure 31](#) uses DACs. An LED tied to the E/S pin through a logic gate indicates if the OPA548 is in thermal shutdown.

[Figure 30](#) illustrates how to use the OPA548 to provide an accurate voltage source with only three external resistors. First, the current limit resistor, R_{CL} , is chosen according to the desired output current. The resulting voltage at the I_{LIM} pin is constant and stable over temperature. This voltage, V_{CL} , is connected to the noninverting input of the operational amplifier and used as a voltage reference, thus eliminating the need for an external reference. The feedback resistors are selected to gain V_{CL} to the desired output voltage level.

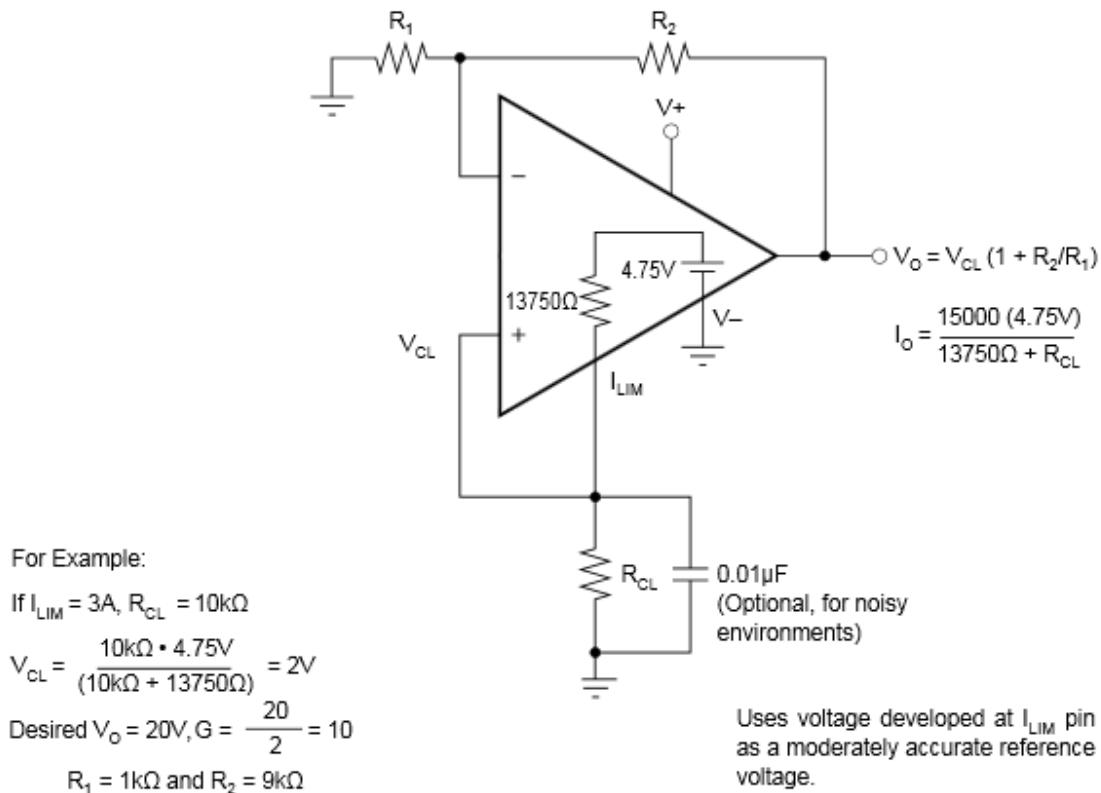


Figure 30. Voltage Source Schematic

Typical Applications (continued)

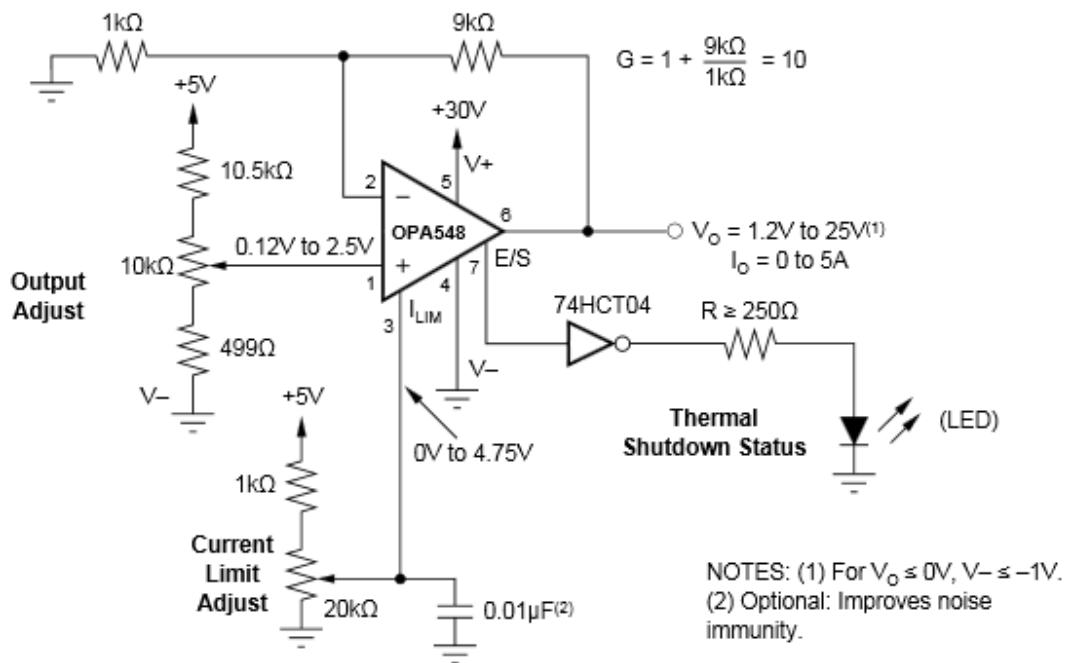


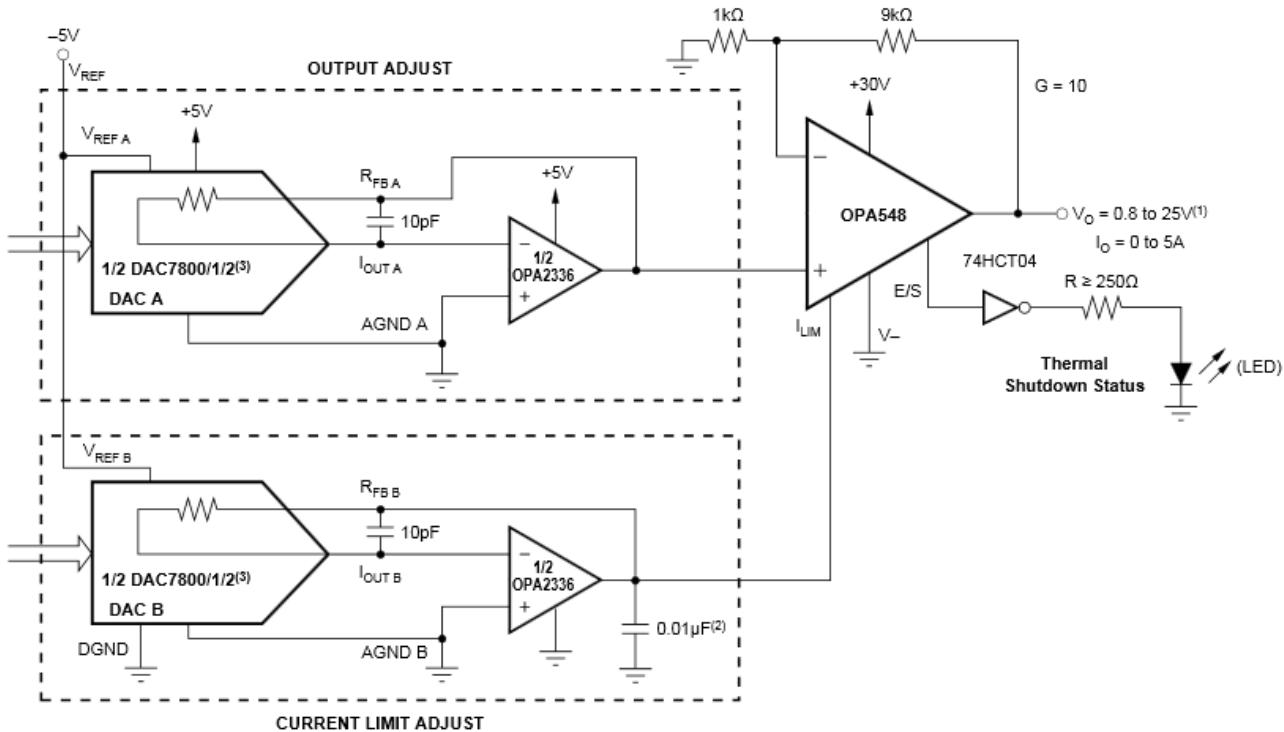
Figure 31. Resistor-Controlled Programmable Power Supply Schematic

OPA548

SBOS070C –OCTOBER 1997–REVISED JUNE 2015

www.ti.com

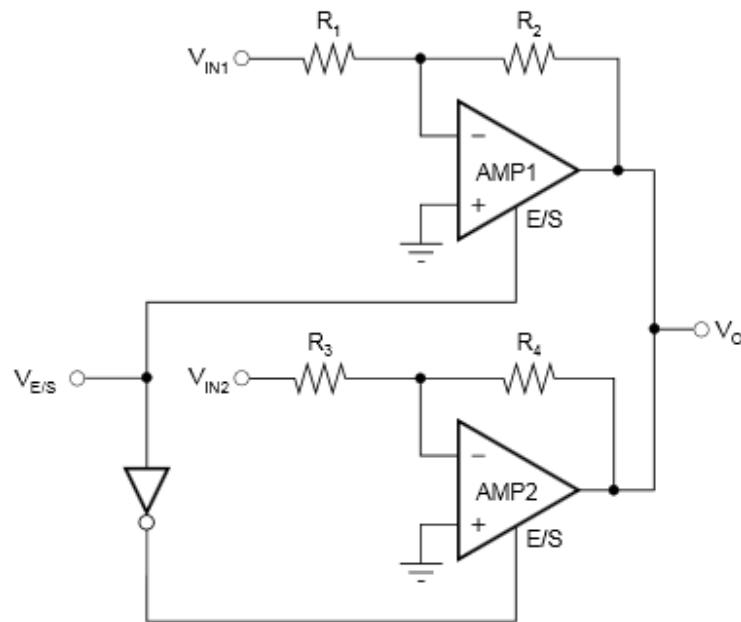
Typical Applications (continued)



NOTES: (1) For $V_O \leq 0V$, $V- \leq -1V$. (2) Optional, improves noise immunity. (3) Choose DAC780X based on digital interface: DAC7800—12-bit interface, DAC7801—8-bit interface + 4 bits, DAC7802—serial interface.

Figure 32. Digitally-Controlled Programmable Power Supply Schematic

9.3 System Examples



$V_{E/S} > (V-) + 2.4V$: Amp 1 is on, Amp 2 if off

$$\rightarrow V_O = -V_{IN1} \left(\frac{R_2}{R_1} \right)$$

$V_{E/S} < (V-) + 2.4V$: Amp 2 is on, Amp 1 if off

$$\rightarrow V_O = -V_{IN2} \left(\frac{R_4}{R_3} \right)$$

Figure 33. Switched Amplifier Schematic

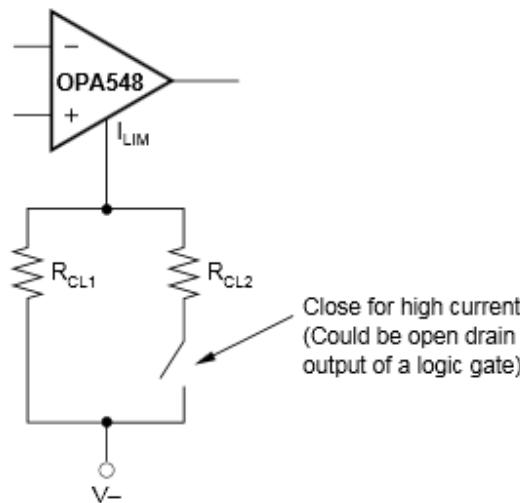


Figure 34. Multiple Current Limit Values Schematic

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

System Examples (continued)

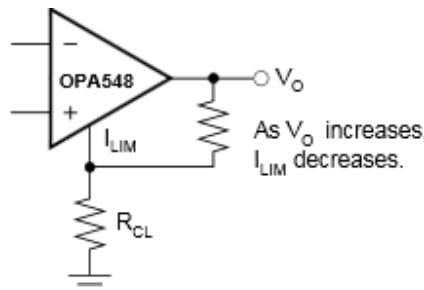
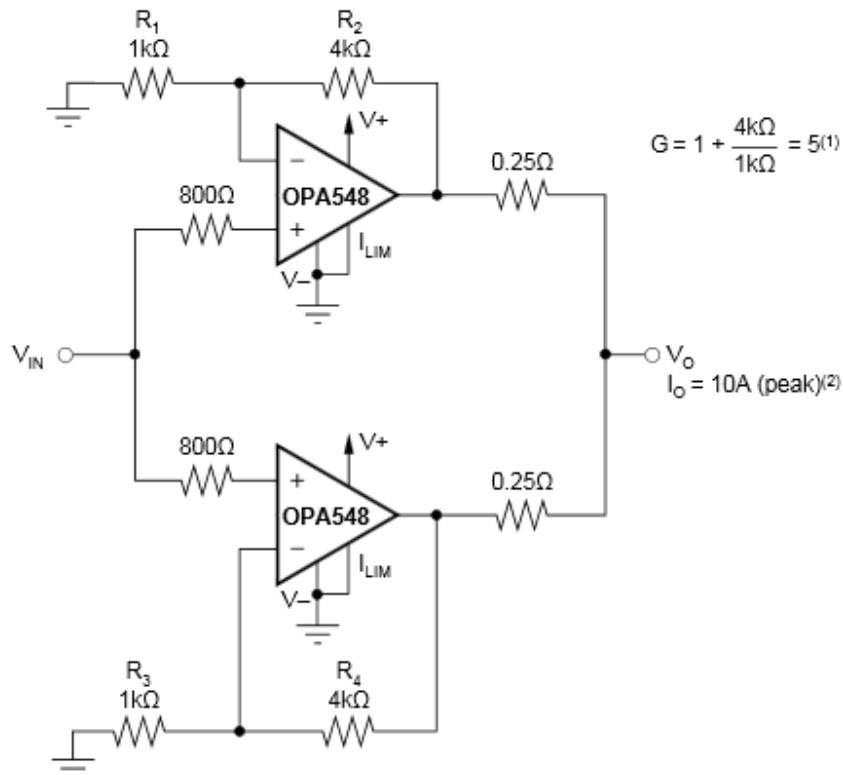


Figure 35. Single Quadrant $V \times I$ Limiting



NOTES: (1) Works well for $G < 10$. Input offset causes output current to flow between amplifiers with $G > 10$. Gains (resistor ratios) of the two amplifiers should be carefully matched to ensure equal current sharing. (2) As configured (I_{LIM} connected to V_-) output current limit is set to 10A (peak). Each amplifier is limited to 5A (peak). Other current limit values may be obtained, see Figure 3, "Adjustable Current Limit".

Figure 36. Parallel Output for Increased Output Current Schematic

10 Power Supply Recommendations

The OPA548 operates from single (8 V to 60 V) or dual (± 4 V to ± 30 V) supplies with excellent performance. Most behavior remains unchanged throughout the full operating voltage range. Parameters which vary significantly with operating voltage are shown [Typical Characteristics](#).

Some applications do not require equal positive and negative output voltage swing. Power-supply voltages do not must be equal. The OPA548 can operate with as little as 8 V between the supplies and with up to 60 V between the supplies. For example, the positive supply could be set to 55 V with the negative supply at -5 V, or vice-versa.

10.1 Output Stage Compensation

The complex load impedances common in power operational amplifier applications can cause output stage instability. For normal operation output compensation circuitry is typically not required. However, if the OPA548 is intended to be driven into current limit, an R/C network may be required. See [Figure 38](#) for an output series R/C compensation (snubber) network which generally provides excellent stability.

A snubber circuit may also enhance stability when driving large capacitive loads ($> 1000 \text{ pF}$) or inductive loads (motors, loads separated from the amplifier by long cables). Typically 3Ω to 10Ω in series with $0.01 \mu\text{F}$ to $0.1 \mu\text{F}$ is adequate. Some variations in circuit value may be required with certain loads.

10.2 Output Protection

Reactive and EMF-generating loads can return load current to the amplifier, causing the output voltage to exceed the power-supply voltage. This damaging condition can be avoided with clamp diodes from the output terminal to the power supplies, as shown in [Figure 38](#). Schottky rectifier diodes with a 5 A or greater continuous rating are recommended.

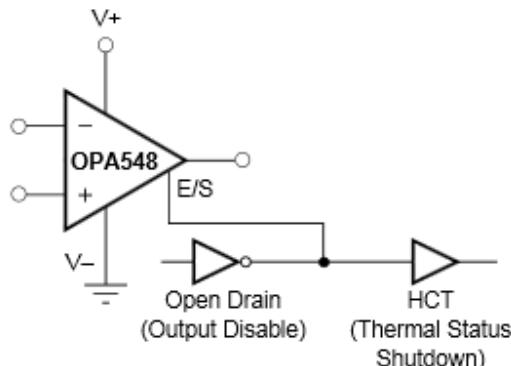


Figure 37. Output Disable and Thermal Shutdown Status With a Single Supply

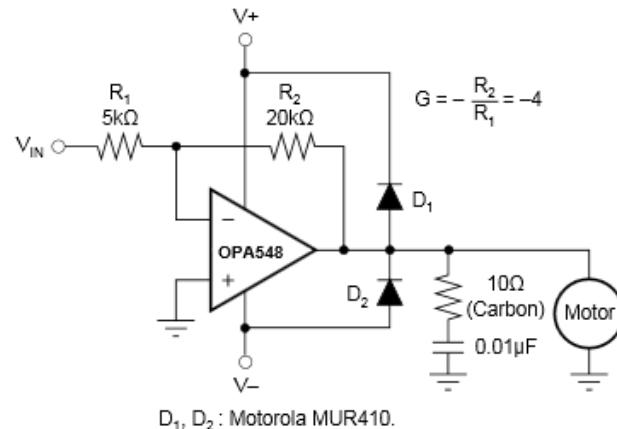


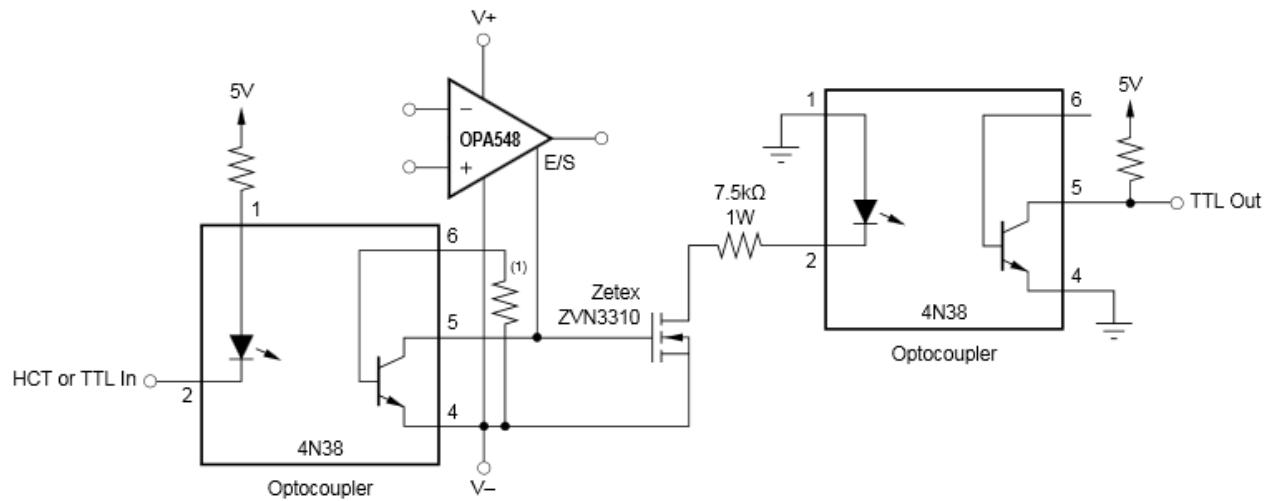
Figure 38. Motor Drive Circuit

OPA548

SBOS070C –OCTOBER 1997–REVISED JUNE 2015

www.ti.com

Output Protection (continued)



NOTE: (1) Optional—may be required to limit leakage current of optocoupler at high temperatures.

Figure 39. Output Disable and Thermal Shutdown Status With Dual Supplies

11 Layout

11.1 Layout Guidelines

11.1.1 Safe Operating Area

Stress on the output transistors is determined both by the output current and by the output voltage across the conducting output transistor, $V_S - V_O$. The power dissipated by the output transistor is equal to the product of the output current and the voltage across the conducting transistor, $V_S - V_O$. The Safe Operating Area (SOA curve, Figure 40) shows the permissible range of voltage and current.

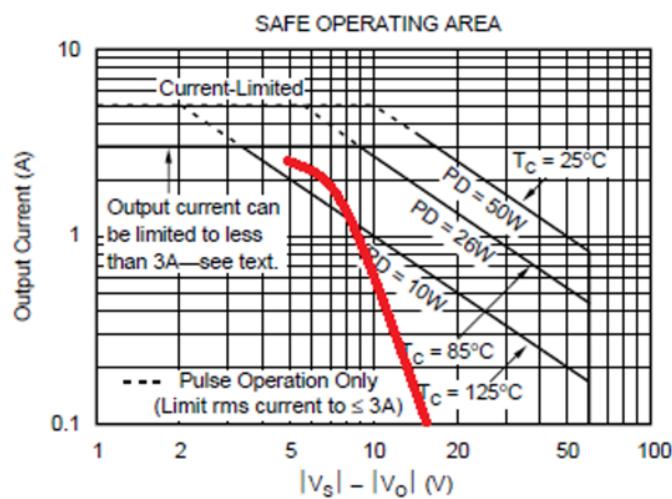


Figure 40. 4- Ω Load Plotted on OPA548 SOA for this Application

The safe output current decreases as $V_S - V_O$ increases. Output short circuits are a very demanding case for SOA. A short-circuit to ground forces the full power-supply voltage (V_+ or V_-) across the conducting transistor. Increasing the case temperature reduces the safe output current that can be tolerated without activating the thermal shutdown circuit of the OPA548. For further insight on SOA, consult Application Bulletin [SBOA022](#).

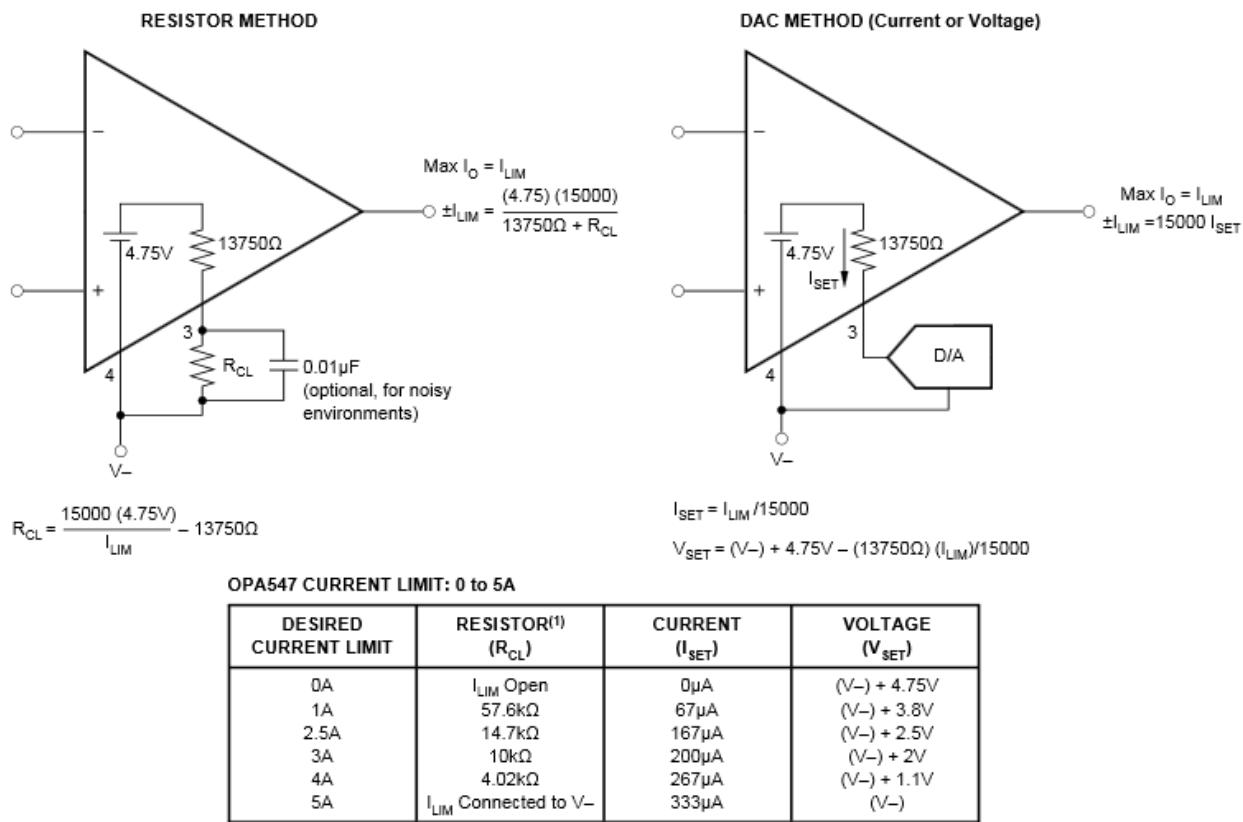
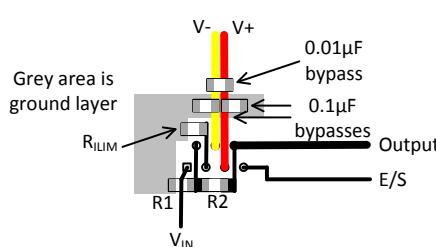
11.1.2 Amplifier Mounting

[Figure 46](#) provides recommended solder footprints for both the TO-220 and DDPAK power packages. The tab of both packages is electrically connected to the negative supply, V_- . It may be desirable to isolate the tab of the TO-220 package from its mounting surface with a mica (or other film) insulator (see [Figure 43](#)). For lowest overall thermal resistance it is best to isolate the entire heat sink/OPA548 structure from the mounting surface rather than to use an insulator between the semiconductor and heat sink.

For best thermal performance, the tab of the DDPAK surface-mount version should be soldered directly to a circuit board copper area. Increasing the copper area improves heat dissipation. See [Figure 44](#) for typical thermal resistance from junction-to-ambient as a function of the copper area.

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com
Layout Guidelines (continued)

Figure 41. Adjustable Current Limit
11.2 Layout Example

Figure 42. Recommended Layout Example
11.3 Power Dissipation

Power dissipation depends on power supply, signal, and load conditions. For DC signals, power dissipation is equal to the product of output current times the voltage across the conducting output transistor. Power dissipation can be minimized by using the lowest possible power-supply voltage necessary to assure the required output voltage swing.

For resistive loads, the maximum power dissipation occurs at a DC output voltage of one-half the power-supply voltage. Dissipation with AC signals is lower. Application Bulletin [SBOA022](#) explains how to calculate or measure power dissipation with unusual signals and loads.

Power Dissipation (continued)

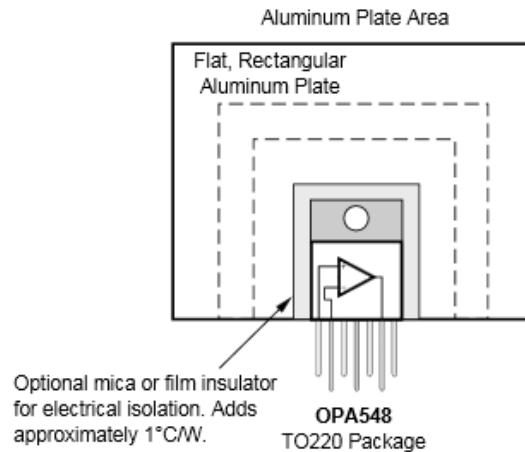
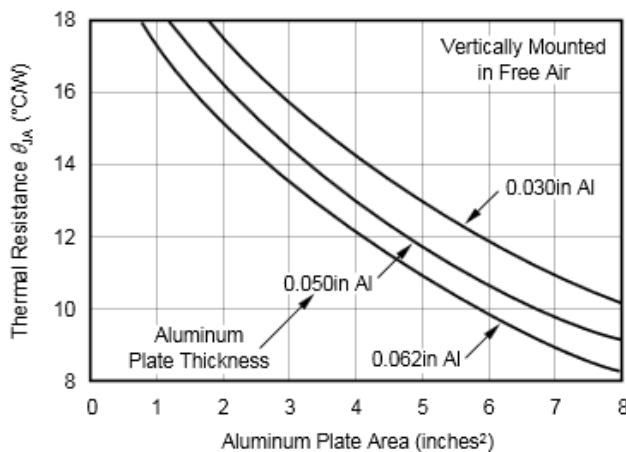


Figure 43. TO-220 Thermal Resistance vs Aluminum Plate Area

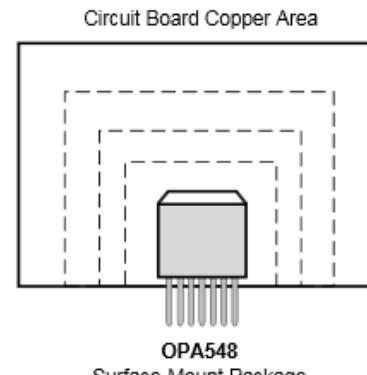
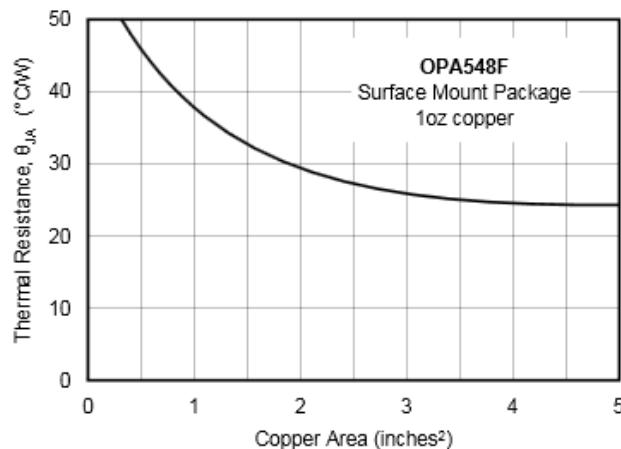


Figure 44. DDPAK Thermal Resistance vs Circuit Board Copper Area

11.4 Thermal Considerations

Power dissipated in the OPA548 will cause the junction temperature to rise. The OPA548 has thermal shutdown circuitry that protects the amplifier from damage. The thermal protection circuitry disables the output when the junction temperature reaches approximately 160°C, allowing the device to cool. When the junction temperature cools to approximately 140°C, the output circuitry is again enabled. Depending on load and signal conditions, the thermal protection circuit may cycle on and off. This limits the dissipation of the amplifier but may have an undesirable effect on the load.

Any tendency to activate the thermal protection circuit indicates excessive power dissipation or an inadequate heat sink. For reliable operation, junction temperature should be limited to 125°C, maximum. To estimate the margin of safety in a complete design (including heat sink) increase the ambient temperature until the thermal protection is triggered. Use worst-case load and signal conditions. For good reliability, thermal protection should trigger more than 35°C more than the maximum expected ambient condition of your application. This produces a junction temperature of 125°C at the maximum expected ambient condition.

The internal protection circuitry of the OPA548 was designed to protect against overload conditions. It was not intended to replace proper heat sinking. Continuously running the OPA548 into thermal shutdown will degrade reliability.

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

11.5 Heat Sinking

Most applications require a heat sink to assure that the maximum operating junction temperature (125°C) is not exceeded. In addition, the junction temperature should be kept as low as possible for increased reliability. Junction temperature can be determined according to the equation:

$$T_J = T_A + P_D R_{\theta JA}$$

where

- $R_{\theta JA} = R_{\theta JC} + R_{\theta CH} + R_{\theta HA}$
- T_J = Junction Temperature (°C)
- T_A = Ambient Temperature (°C)
- P_D = Power Dissipated (W)
- $R_{\theta JC}$ = Junction-to-Case Thermal Resistance (°C/W)
- $R_{\theta CH}$ = Case-to-Heat Sink Thermal Resistance (°C/W)
- $R_{\theta HA}$ = Heat Sink-to-Ambient Thermal Resistance (°C/W)
- $R_{\theta JA}$ = Junction-to-Air Thermal Resistance (°C/W)

(2)

Figure 45 shows maximum power dissipation versus ambient temperature with and without the use of a heat sink. Using a heat sink significantly increases the maximum power dissipation at a given ambient temperature as shown.

The difficulty in selecting the heat sink required lies in determining the power dissipated by the OPA548. For DC output into a purely resistive load, power dissipation is simply the load current times the voltage developed across the conducting output transistor, $P_D = I_L(V_S - V_O)$. Other loads are not as simple. Consult Application Bulletin SBOA022 for further insight on calculating power dissipation. Once power dissipation for an application is known, the proper heat sink can be selected.

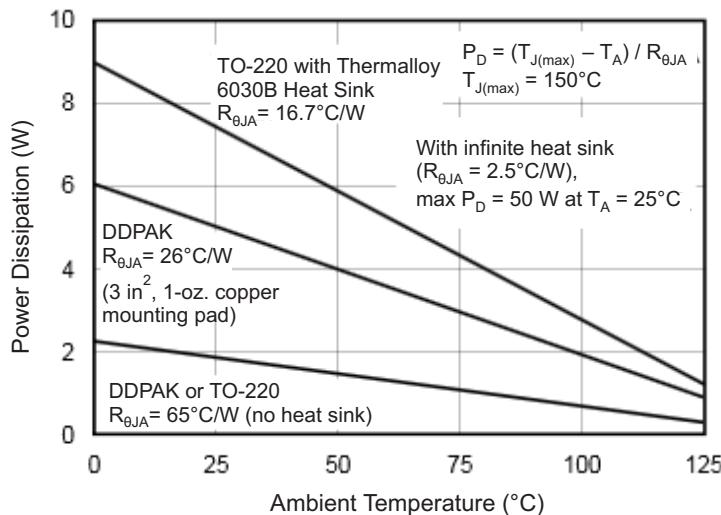


Figure 45. Maximum Power Dissipation vs Ambient Temperature

11.5.1 Heat Sink Selection Example

A TO-220 package is dissipating 5 W. The maximum expected ambient temperature is 40°C. Find the proper heat sink to keep the junction temperature less than 125°C (150°C minus 25°C safety margin).

Combining [Equation 2](#) and [Equation 3](#) gives:

$$T_J = T_A + P_D(R_{\theta JC} + R_{\theta CH} + R_{\theta HA}) \quad (3)$$

T_J , T_A , and P_D are given. $R_{\theta JC}$ is provided in the specification table, 2.5°C/W (DC). $R_{\theta CH}$ can be obtained from the heat sink manufacturer. Its value depends on heat sink size, area, and material used. Semiconductor package type, mounting screw torque, insulating material used (if any), and thermal joint compound used (if any) also affect $R_{\theta CH}$. A typical $R_{\theta CH}$ for a TO-220 mounted package is 1°C/W. Now we can solve for $R_{\theta HA}$:

Heat Sinking (continued)

$$\theta_{HA} = \frac{T_J - T_A}{P_D} - (\theta_{JC} + \theta_{CH})$$

$$\theta_{HA} = \frac{125^\circ\text{C} - 40^\circ\text{C}}{5\text{W}} - (2.5^\circ\text{C} / \text{W} + 1^\circ\text{C} / \text{W}) = 13.5^\circ\text{C} / \text{W} \quad (4)$$

To maintain junction temperature less than 125°C, the heat sink selected must have a $R_{\theta HA}$ less than 14°C/W. In other words, the heat sink temperature rise above ambient must be less than 67.5°C (13.5°C/W \times 5 W). For example, at 5-W Thermalloy model number 6030B has a heat sink temperature rise of 66°C more than ambient ($R_{\theta HA} = 66^\circ\text{C} / 5\text{W} = 13.2^\circ\text{C} / \text{W}$), which is less than the 67.5°C required in this example. [Figure 45](#) shows power dissipation versus ambient temperature for a TO-220 package with a 6030B heat sink.

Another variable to consider is natural convection versus forced convection air flow. Forced-air cooling by a small fan can lower $R_{\theta JCA}$ ($R_{\theta CH} + R_{\theta HA}$) dramatically. Heat sink manufacturers provide thermal data for both of these cases. For additional information on determining heat sink requirements, consult Application Bulletin [SBOA021](#).

As mentioned earlier, once a heat sink has been selected, the complete design should be tested under worst-case load and signal conditions to ensure proper thermal protection.

OPA548

SBOS070C – OCTOBER 1997 – REVISED JUNE 2015

www.ti.com

12 Device and Documentation Support

12.1 Device Support

12.1.1 Third-Party Products Disclaimer

TI'S PUBLICATION OF INFORMATION REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT CONSTITUTE AN ENDORSEMENT REGARDING THE SUITABILITY OF SUCH PRODUCTS OR SERVICES OR A WARRANTY, REPRESENTATION OR ENDORSEMENT OF SUCH PRODUCTS OR SERVICES, EITHER ALONE OR IN COMBINATION WITH ANY TI PRODUCT OR SERVICE.

12.2 Documentation Support

12.2.1 Related Documentation

Heat Sinking — TO-3 Thermal Model, [SBOA021](#)

12.3 Community Resources

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

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

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

12.4 Trademarks

E2E is a trademark of Texas Instruments.

All other trademarks are the property of their respective owners.

12.5 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

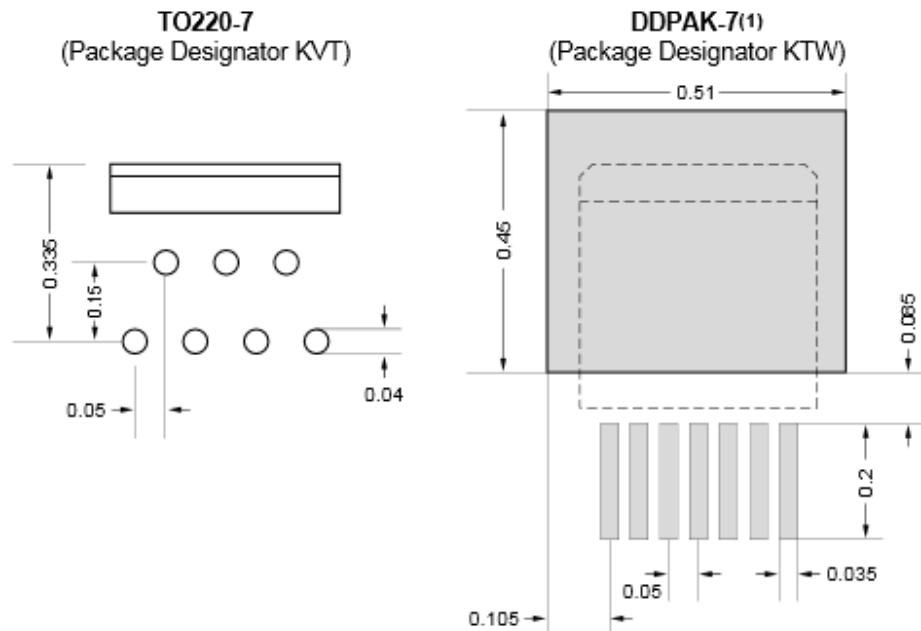
12.6 Glossary

[SLYZ022](#) — **TI Glossary.**

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

13 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.



- (1) For improved thermal performance, increase footprint area. See [Figure 44](#).
- (2) Mean dimensions in inches. Refer to the mechanical drawings or www.ti.com for tolerances and detailed package drawings.

Figure 46. TO-220 and DDPAK Solder Footprints

PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|------------------|---------------|------------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|----------------|
| OPA548F | OBsolete | DDPAK/ TO-263 | KTW | 7 | | TBD | Call TI | Call TI | | | |
| OPA548F/500 | ACTIVE | DDPAK/ TO-263 | KTW | 7 | 500 | Green (RoHS & no Sb/Br) | CU SN | Level-2-260C-1 YEAR | -40 to 85 | OPA548F | Samples |
| OPA548F/500G3 | ACTIVE | DDPAK/ TO-263 | KTW | 7 | 500 | Green (RoHS & no Sb/Br) | CU SN | Level-2-260C-1 YEAR | -40 to 85 | OPA548F | Samples |
| OPA548FKTWT | ACTIVE | DDPAK/ TO-263 | KTW | 7 | 50 | Green (RoHS & no Sb/Br) | CU SN | Level-2-260C-1 YEAR | -40 to 85 | OPA548F | Samples |
| OPA548FKTWTG3 | ACTIVE | DDPAK/ TO-263 | KTW | 7 | 50 | Green (RoHS & no Sb/Br) | CU SN | Level-2-260C-1 YEAR | -40 to 85 | OPA548F | Samples |
| OPA548T | ACTIVE | TO-220 | KVT | 7 | 50 | Green (RoHS & no Sb/Br) | CU SN | N / A for Pkg Type | -40 to 85 | OPA548T | Samples |
| OPA548T-1 | ACTIVE | TO-220 | KC | 7 | 50 | Green (RoHS & no Sb/Br) | CU SN | N / A for Pkg Type | -40 to 85 | OPA548T | Samples |
| OPA548T-1G3 | ACTIVE | TO-220 | KC | 7 | 50 | Green (RoHS & no Sb/Br) | CU SN | N / A for Pkg Type | -40 to 85 | OPA548T | Samples |
| OPA548TG3 | ACTIVE | TO-220 | KVT | 7 | 50 | Green (RoHS & no Sb/Br) | CU SN | N / A for Pkg Type | -40 to 85 | OPA548T | Samples |

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBsolete: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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

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

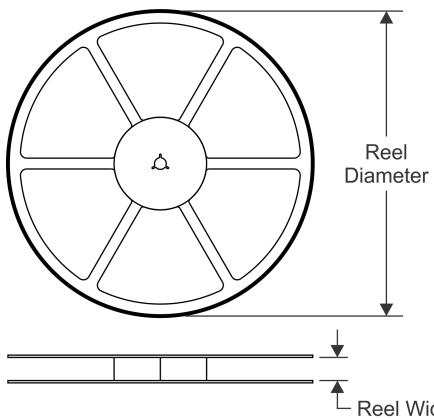
⁽⁶⁾ Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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

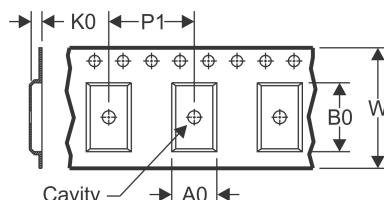
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

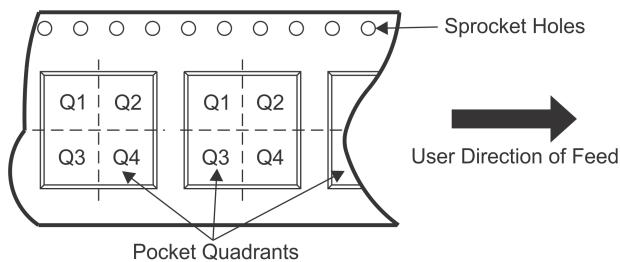


TAPE DIMENSIONS



| | |
|----|---|
| 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 |

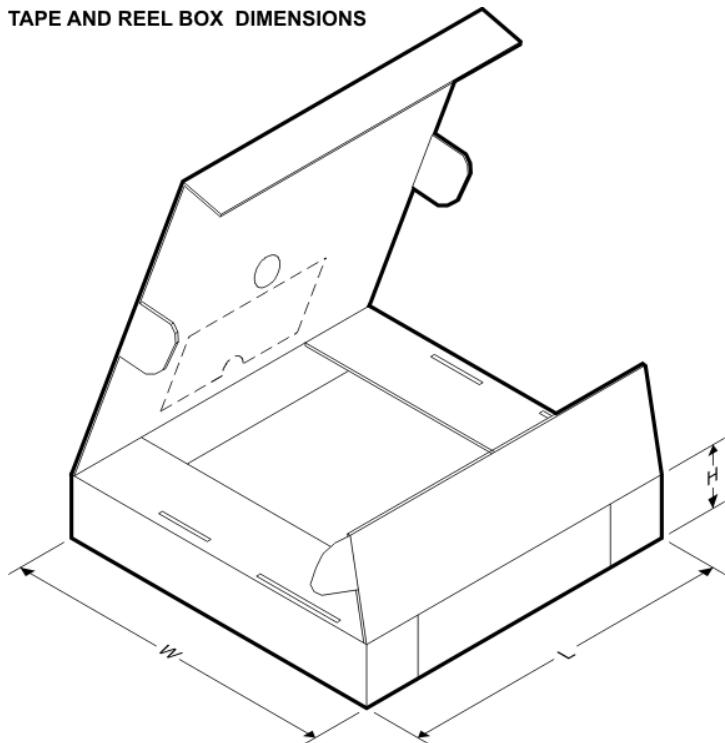
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|-------------|--------------|-----------------|------|-----|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| OPA548F/500 | DDPAK/TO-263 | KTW | 7 | 500 | 330.0 | 24.4 | 10.95 | 16.5 | 5.15 | 16.0 | 24.0 | Q2 |
| OPA548FKTWT | DDPAK/TO-263 | KTW | 7 | 50 | 330.0 | 24.4 | 10.6 | 15.6 | 4.9 | 16.0 | 24.0 | Q2 |

TAPE AND REEL BOX DIMENSIONS



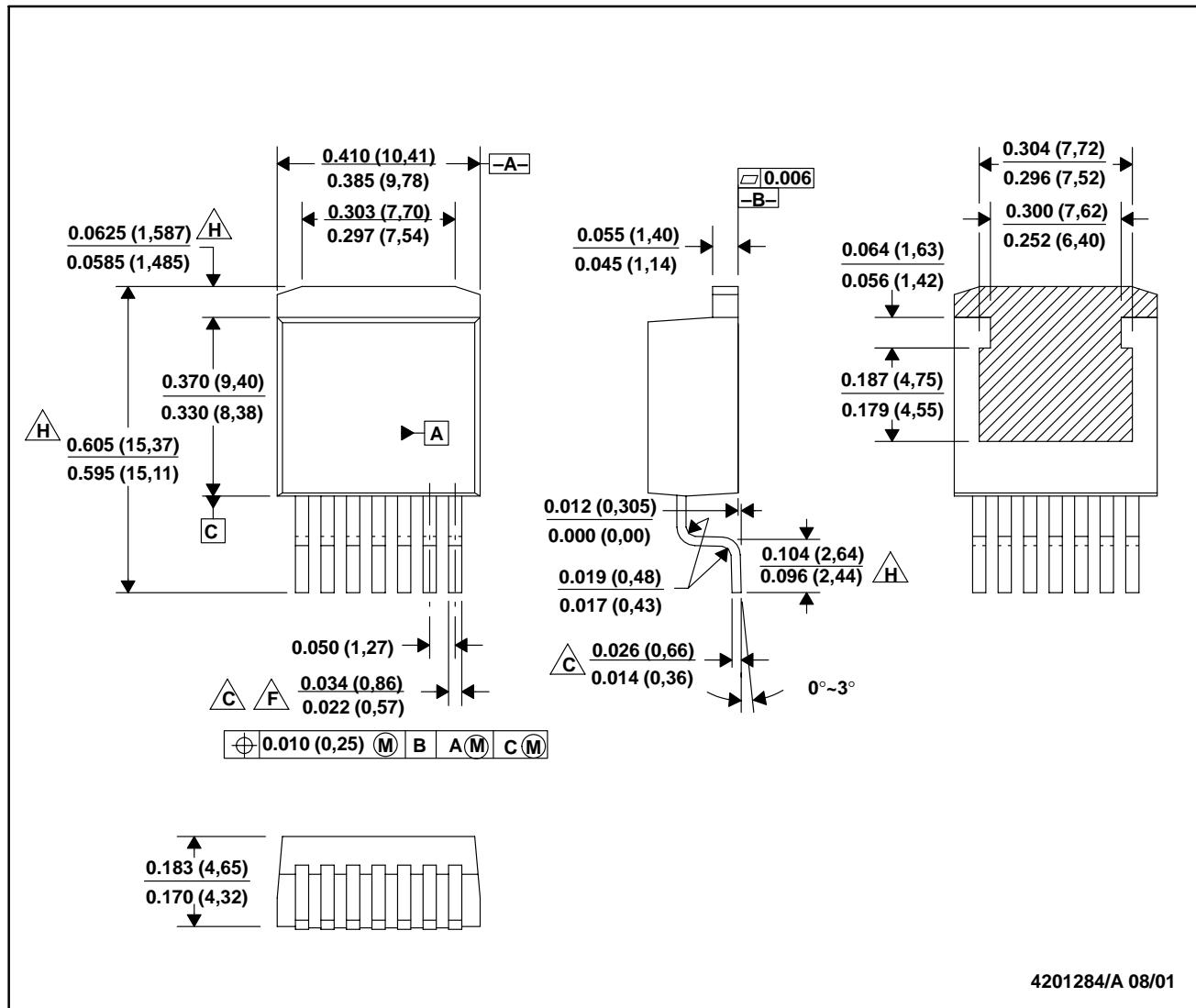
*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|-------------|--------------|-----------------|------|-----|-------------|------------|-------------|
| OPA548F/500 | DDPAK/TO-263 | KTW | 7 | 500 | 346.0 | 346.0 | 41.0 |
| OPA548FKTWT | DDPAK/TO-263 | KTW | 7 | 50 | 367.0 | 367.0 | 45.0 |

MPSF015 – AUGUST 2001

KTW (R-PSFM-G7)

PLASTIC FLANGE-MOUNT

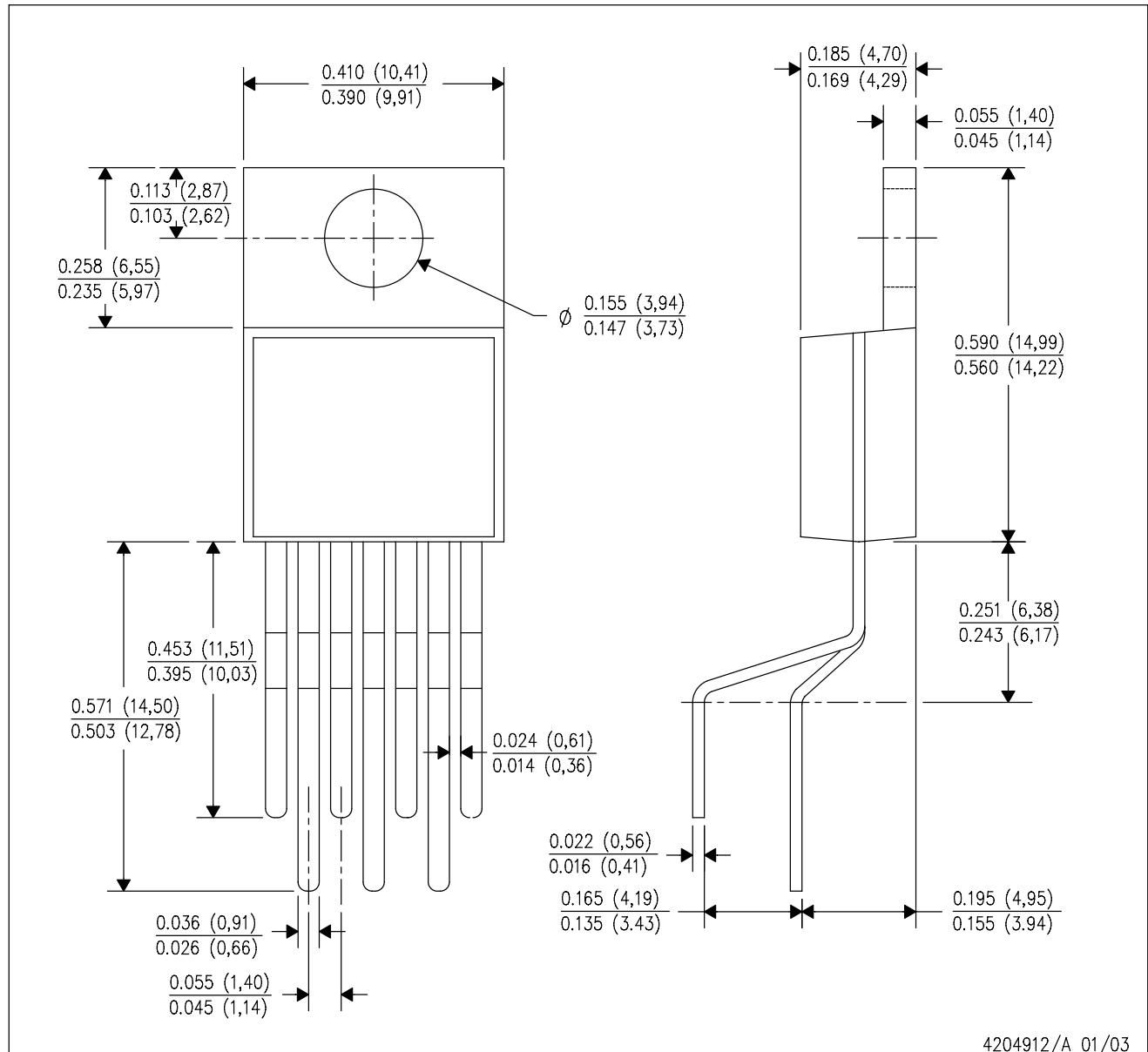


NOTES:

- All linear dimensions are in inches (millimeters).
- This drawing is subject to change without notice.
- Lead width and height dimensions apply to the plated lead.
- Leads are not allowed above the Datum B.
- Stand-off height is measured from lead tip with reference to Datum B.
- Lead width dimension does not include dambar protrusion. Allowable dambar protrusion shall not cause the lead width to exceed the maximum dimension by more than 0.003".
- Cross-hatch indicates exposed metal surface.
- Falls within JEDEC MO-169 with the exception of the dimensions indicated.

KVT (R-PZFM-T7)

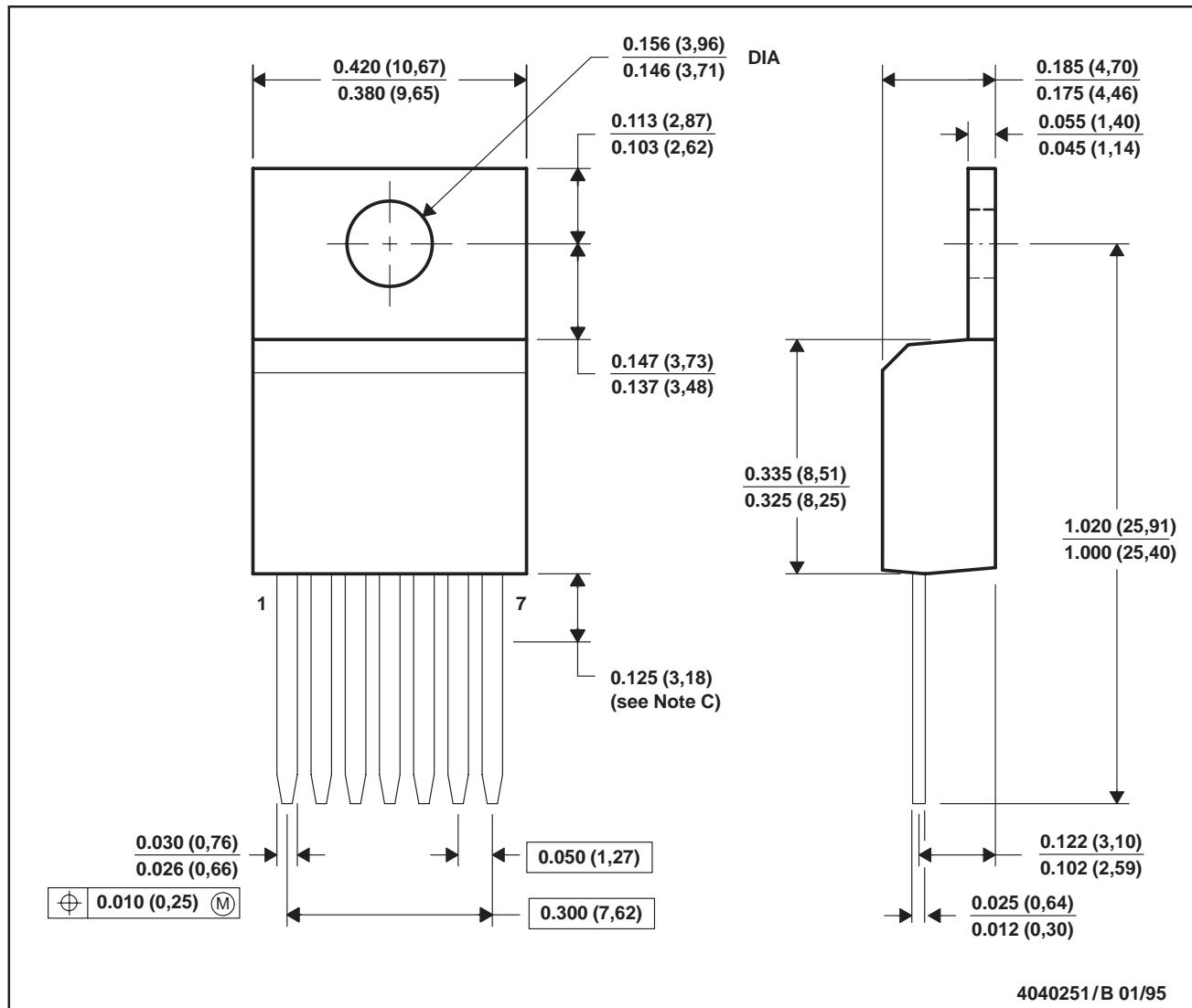
PLASTIC FLANGE MOUNT PACKAGE



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.

KC (R-PSFM-T7)

PLASTIC FLANGE-MOUNT PACKAGE



NOTES:

- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Lead dimensions are not controlled within this area.
- D. All lead dimensions apply before solder dip.
- E. The center lead is in electrical contact with the mounting tab.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

| | |
|------------------------------|--|
| Audio | www.ti.com/audio |
| Amplifiers | amplifier.ti.com |
| Data Converters | dataconverter.ti.com |
| DLP® Products | www.dlp.com |
| DSP | dsp.ti.com |
| Clocks and Timers | www.ti.com/clocks |
| Interface | interface.ti.com |
| Logic | logic.ti.com |
| Power Mgmt | power.ti.com |
| Microcontrollers | microcontroller.ti.com |
| RFID | www.ti-rfid.com |
| OMAP Applications Processors | www.ti.com/omap |
| Wireless Connectivity | www.ti.com/wirelessconnectivity |

Applications

| | |
|-------------------------------|--|
| Automotive and Transportation | www.ti.com/automotive |
| Communications and Telecom | www.ti.com/communications |
| Computers and Peripherals | www.ti.com/computers |
| Consumer Electronics | www.ti.com/consumer-apps |
| Energy and Lighting | www.ti.com/energy |
| Industrial | www.ti.com/industrial |
| Medical | www.ti.com/medical |
| Security | www.ti.com/security |
| Space, Avionics and Defense | www.ti.com/space-avionics-defense |
| Video and Imaging | www.ti.com/video |

TI E2E Communitye2e.ti.com