

# OPA548 高電圧、大電流オペアンプ

## 1 特長

- 広い電源電圧範囲
  - シングル電源: 8V~60V
  - デュアル電源:  $\pm 4V \sim \pm 30V$
- 大きな出力電流
  - 連続 3A
  - ピーク 5A
- 大きな出力電圧振幅
- 包括的な保護機能
  - サーマル・シャットダウン
  - 可変電流制限
- 出力ディセーブル制御
- サーマル・シャットダウン・インジケータ
- 高スルーレート: 10V/ $\mu s$
- 低静止電流
- パッケージ
  - 7 リードの TO-220、zip およびストレート・リード
  - 7 リードの DDPACK 表面実装

## 2 アプリケーション

- 半導体製造
- 半導体試験装置
- 実験室およびフィールド用計測機器
- LCD テスト
- アナログ入力モジュール
- 超音波スキャナ

## 3 概要

OPA548 デバイスは、さまざまな負荷を駆動するように設計された低コスト、高電圧、大電流のオペアンプです。レーザー・トリムされたモノリシック集積回路により、非常に優れた小信号精度と大きな出力電圧および電流を実現しています。

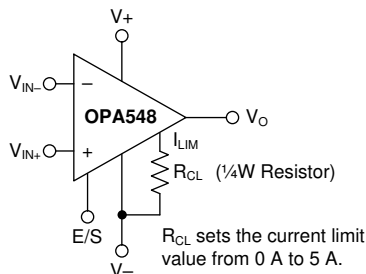
OPA548 はシングル電源とデュアル電源のどちらでも動作するため、柔軟な設計が可能です。シングル電源動作では、入力同相範囲がグランドより下まで到達します。

OPA548 は、過熱状態と電流過負荷に対して内部的に保護されています。さらに OPA548 には、ユーザーが選択可能な高精度の電流制限機能を備えています。出力電流経路と直列にパワー抵抗を使用するその他の設計とは異なり、OPA548 は負荷を間接的に測定します。電流制限値は外付け抵抗とポテンショメータによって 0A~5A の範囲に設定でき、電圧出力または電流出力 DAC を使用してデジタル制御することもできます。

イネーブル / ステータス (E/S) ピンには 2 つの機能があります。このピンの入力は出力段をディセーブルして実質的に負荷を切断するだけでなく、静止電流を減らして電力を節減します。E/S ピンの出力を監視することで、OPA548 がサーマル・シャットダウン状態にあるかどうかを判断できます。

OPA548 デバイスは、業界標準の 7 リードの千鳥配列および直線リードの TO-220 パッケージと、7 リード DDPACK 表面実装プラスチック・パワー・パッケージで供給されます。銅のタブによりヒートシンクまたは基板に簡単に実装でき、非常に優れた熱性能が得られます。このデバイスは、拡張産業用温度範囲の  $-40^{\circ}C \sim 85^{\circ}C$  で動作が規定されています。設計解析用の SPICE マクロモデルが利用できます。

概略回路図



製品情報<sup>(1)</sup>

| 型番     | パッケージ      | 本体サイズ(公称)        |
|--------|------------|------------------|
| OPA548 | TO-220 (7) | 10.17mm × 8.38mm |
|        | TO-263 (7) | 10.10mm × 8.89mm |

(1) 利用可能なすべてのパッケージについては、このデータシートの末尾にあるパッケージ・オプションについての付録を参照してください。

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## 4 改訂履歴

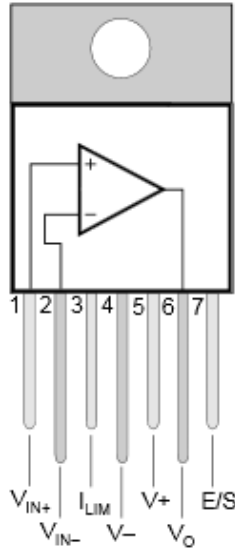
資料番号末尾の英字は改訂を表しています。その改訂履歴は英語版に準じています。

| Revision C (June 2015) から Revision D に変更                                                                                                             | Page |
|------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| • Changed all INPUT BIAS CURRENT specifications in MIN column to TYP column, and all specifications in TYP column to MAX column (typo) .....         | 5    |
| • Changed <i>Quiescent current</i> , <i>shutdown mode</i> parameter unit typo from nA to mA in <i>Electrical Characteristics</i> table .....         | 6    |
| • Deleted <i>Temperature Range</i> section of <i>Electrical Characteristics</i> table; content already available in other specifications tables..... | 6    |
| • Changed Figure 20 x-axis label from 2 $\mu$ s/div to 5 $\mu$ s/div, and y-axis label from 50 mV/div to 10 V/div .....                              | 10   |

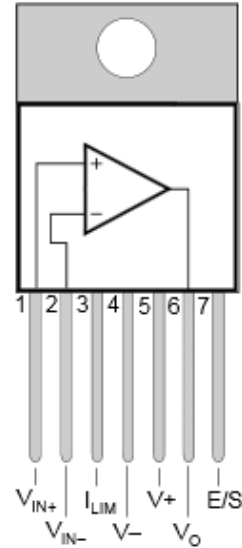
| Revision B (October 2003) から Revision C に変更                                                                                                               | Page |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| • 「ESD 定格」表、「機能説明」セクション、「デバイスの機能モード」セクション、「アプリケーションと実装」セクション、「電源に関する推奨事項」セクション、「レイアウト」セクション、「デバイスおよびドキュメントのサポート」セクション、「メカニカル、パッケージ、および注文情報」セクション 追加 ..... | 1    |

## 5 Pin Configuration and Functions

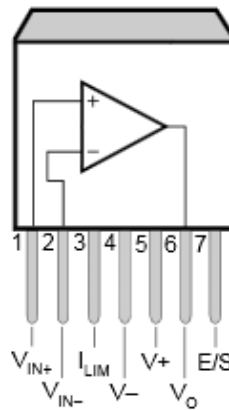
**KVT and KC Packages Stagger-Formed  
7-Pin TO-220  
Top View**



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



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



### Pin Functions

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

## 6 Specifications

### 6.1 Absolute Maximum Ratings

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

|                  |                          | MIN                           | MAX        | UNIT |
|------------------|--------------------------|-------------------------------|------------|------|
|                  | Output current           | See <a href="#">Figure 40</a> |            |      |
|                  | 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 <sub>stg</sub> | 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.

### 6.2 ESD Ratings

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

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

### 6.3 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   |

### 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | OPA548              |             | UNIT |
|-------------------------------|----------------------------------------------|---------------------|-------------|------|
|                               |                                              | KVT and KC (TO-220) | KTW (DDPAK) |      |
|                               |                                              | 7 PINS              | 7 PINS      |      |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 30.2                | 30.2        | °C/W |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance    | 37.4                | 37.4        | °C/W |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 14.4                | 14.4        | °C/W |
| ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 5.1                 | 5.1         | °C/W |
| ψ <sub>JB</sub>               | Junction-to-board characterization parameter | 14.3                | 14.3        | °C/W |
| R <sub>θJC(bot)</sub>         | 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](#).

## 6.5 Electrical Characteristics

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

| PARAMETER                                        |          | TEST CONDITIONS                                                                                  | MIN                                                        | TYP                | MAX  | UNIT    |
|--------------------------------------------------|----------|--------------------------------------------------------------------------------------------------|------------------------------------------------------------|--------------------|------|---------|
| <b>OFFSET VOLTAGE</b>                            |          |                                                                                                  |                                                            |                    |      |         |
| Input offset voltage                             |          | $V_{CM} = 0\text{ V}$ , $I_O = 0\text{ A}$                                                       |                                                            | ±2                 | ±10  | mV      |
| Input offset voltage drift                       |          | $V_{CM} = 0\text{ V}$ , $I_O = 0\text{ A}$ ,<br>$T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$ |                                                            | ±30                |      | μV/°C   |
| Power-supply rejection ratio                     |          | $V_{CM} = 0\text{ V}$ , $I_O = 0\text{ A}$ ,<br>$V_S = \pm 4\text{ V}$ to $\pm 30\text{ V}$      |                                                            | 30                 | 100  | μV/V    |
| <b>INPUT BIAS CURRENT<sup>(1)</sup></b>          |          |                                                                                                  |                                                            |                    |      |         |
| Input bias current <sup>(2)</sup>                |          | $V_{CM} = 0\text{ V}$                                                                            |                                                            | –100               | –500 | nA      |
| Input bias current drift                         |          | $V_{CM} = 0\text{ V}$ , $T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$                         |                                                            | ±0.5               |      | nA/°C   |
| Input offset current                             |          | $V_{CM} = 0\text{ V}$                                                                            |                                                            | ±5                 | ±50  | nA      |
| <b>NOISE</b>                                     |          |                                                                                                  |                                                            |                    |      |         |
| Input voltage noise density                      |          | $f = 1\text{ kHz}$                                                                               |                                                            | 90                 |      | nV/√Hz  |
| Current noise density                            |          | $f = 1\text{ kHz}$                                                                               |                                                            | 200                |      | fA/√Hz  |
| <b>INPUT VOLTAGE</b>                             |          |                                                                                                  |                                                            |                    |      |         |
| Common-mode voltage                              | Positive | Linear operation                                                                                 | (V+) – 3                                                   | (V+) – 2.3         |      | V       |
|                                                  | Negative | Linear operation                                                                                 | (V–) – 0.1                                                 | (V–) – 0.2         |      |         |
| Common-mode rejection                            |          | $V_{CM} = (V–) - 0.1\text{ V}$ to $(V+) - 3\text{ V}$                                            | 80                                                         | 95                 |      | dB      |
| <b>INPUT IMPEDANCE</b>                           |          |                                                                                                  |                                                            |                    |      |         |
| Differential input impedance                     |          |                                                                                                  |                                                            | $10^7 \parallel 6$ |      | Ω    pF |
| Common-mode input impedance                      |          |                                                                                                  |                                                            | $10^9 \parallel 4$ |      | Ω    pF |
| <b>OPEN-LOOP GAIN</b>                            |          |                                                                                                  |                                                            |                    |      |         |
| Open-loop voltage gain                           |          | $V_O = \pm 25\text{ V}$ , $R_L = 1\text{ k}\Omega$                                               | 90                                                         | 98                 |      | dB      |
|                                                  |          | $V_O = \pm 25\text{ V}$ , $R_L = 8\text{ }\Omega$                                                |                                                            | 90                 |      | dB      |
| <b>FREQUENCY RESPONSE</b>                        |          |                                                                                                  |                                                            |                    |      |         |
| Gain-bandwidth product                           |          | $R_L = 8\text{ }\Omega$                                                                          |                                                            | 1                  |      | MHz     |
| Slew rate                                        |          | $G = 1$ , $V_O = 50\text{ V}_{pp}$ , $R_L = 8\text{ }\Omega$                                     |                                                            | 10                 |      | V/μs    |
| Full-power bandwidth                             |          |                                                                                                  | See <a href="#">Typical Characteristics</a>                |                    |      | kHz     |
| Settling time                                    |          | To ±0.1%, $G = -10$ , $V_O = 50\text{ V}_{pp}$                                                   |                                                            | 15                 |      | μs      |
| Total harmonic distortion + noise <sup>(3)</sup> |          | $f = 1\text{ kHz}$ , $R_L = 8\text{ }\Omega$ , $G = 3$ ,<br>Power = 10 W                         |                                                            | 0.02%              |      |         |
| <b>OUTPUT</b>                                    |          |                                                                                                  |                                                            |                    |      |         |
| Voltage output                                   | Positive | $I_O = 3\text{ A}$                                                                               | (V+) – 4.1                                                 | (V+) – 3.7         |      | V       |
|                                                  | Negative | $I_O = -3\text{ A}$                                                                              | (V–) + 3.7                                                 | (V–) + 3.3         |      |         |
|                                                  | Positive | $I_O = 0.6\text{ A}$                                                                             | (V+) – 2.4                                                 | (V+) – 2.1         |      |         |
|                                                  | Negative | $I_O = -0.6\text{ A}$                                                                            | (V–) + 1.3                                                 | (V–) + 1.0         |      |         |
| Maximum continuous current output                | DC       |                                                                                                  | ±3                                                         |                    |      | A       |
|                                                  | AC       |                                                                                                  | 3                                                          |                    |      | Arms    |
| Leakage current, output disabled, dc             |          |                                                                                                  | See <a href="#">Typical Characteristics</a>                |                    |      |         |
| Output current limit                             |          |                                                                                                  | –5                                                         |                    | 5    | A       |
| Output current limit equation                    |          |                                                                                                  | $I_{LIM} = (15000)(4.75) / (13750\text{ }\Omega + R_{CL})$ |                    |      | A       |
| Output current limit tolerance <sup>(1)</sup>    |          | $R_{CL} = 14.8\text{ k}\Omega$ ( $I_{LIM} = \pm 2.5\text{ A}$ ),<br>$R_L = 8\text{ }\Omega$      |                                                            | ±100               | ±250 | mA      |
| Capacitive load drive                            |          |                                                                                                  | See <a href="#">Figure 19</a>                              |                    |      |         |

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

(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 |
|-----------------------------------------|----------------------------------------|---------------------------------------------------------------------|--------------------------|-------------------------|-------------------------|------|
| OUTPUT ENABLE /STATUS (E/S) PIN         |                                        |                                                                     |                          |                         |                         |      |
| Shutdown input mode                     | V <sub>E/S</sub> HIGH (output enabled) | E/S pin open or forced high                                         | (V <sub>−</sub> ) + 2.4  |                         | (V <sub>−</sub> ) + 0.8 | V    |
|                                         | V <sub>E/S</sub> LOW (output disabled) | E/S pin forced low                                                  |                          |                         |                         |      |
|                                         | I <sub>E/S</sub> HIGH (output enabled) | E/S pin high                                                        | −65                      |                         | μA                      |      |
|                                         | I <sub>E/S</sub> LOW (output disabled) | E/S pin low                                                         | −70                      |                         |                         |      |
| Output disable time                     |                                        |                                                                     | 1                        |                         | μs                      |      |
| Output enable time                      |                                        |                                                                     | 3                        |                         | μs                      |      |
| Thermal shutdown status output          |                                        | Normal operation, sourcing 20 μA                                    | (V <sub>−</sub> ) + 2.4  | (V <sub>−</sub> ) + 3.5 | (V <sub>−</sub> ) + 0.8 | V    |
|                                         |                                        | Thermally shut down, sinking 5 μA, T <sub>J</sub> > 160°C           | (V <sub>−</sub> ) + 0.35 |                         |                         |      |
| Thermal protection junction temperature |                                        | Shutdown                                                            | 160                      |                         |                         | °C   |
|                                         |                                        | Reset from shutdown                                                 | 140                      |                         |                         |      |
| POWER SUPPLY                            |                                        |                                                                     |                          |                         |                         |      |
| Quiescent current                       |                                        | I <sub>LIM</sub> connected to V <sub>−</sub> , I <sub>O</sub> = 0 A | ±17                      |                         | ±20                     | mA   |
| Quiescent current, shutdown mode        |                                        | I <sub>LIM</sub> connected to V <sub>−</sub> , I <sub>O</sub> = 0 A | ±6                       |                         |                         | mA   |

## 6.6 Typical Characteristics

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

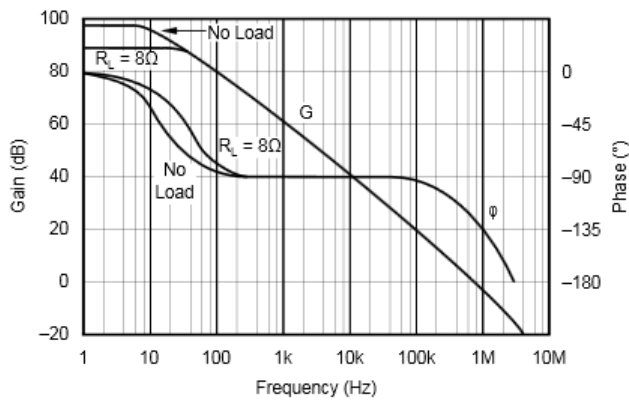


Figure 1. Open-Loop Gain and Phase vs Frequency

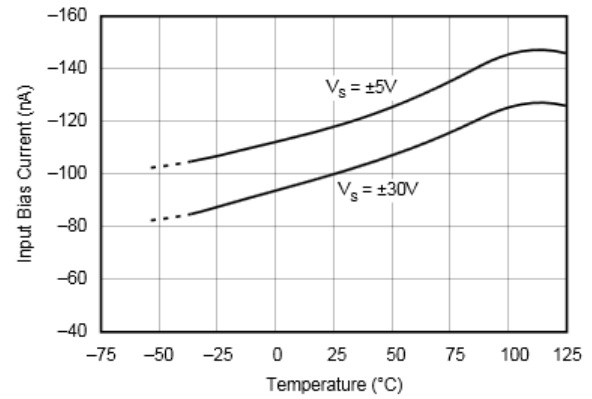


Figure 2. Input Bias Current vs Temperature

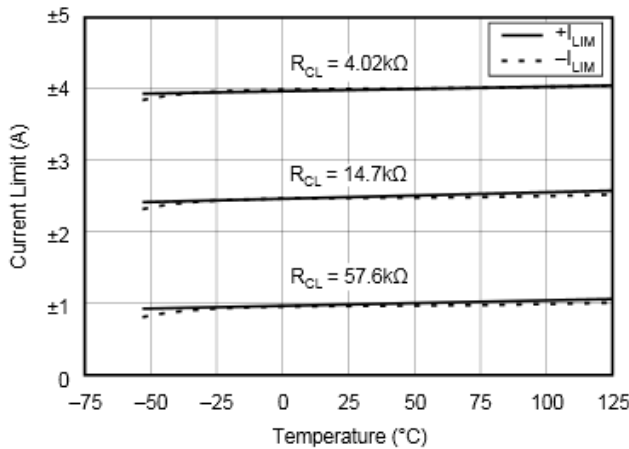


Figure 3. Current Limit vs Temperature

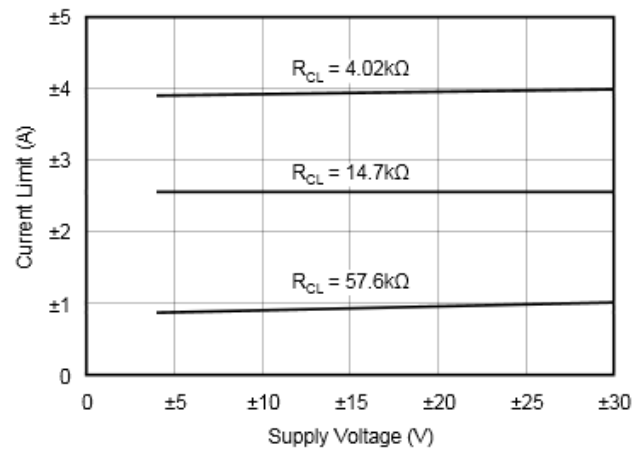


Figure 4. Current Limit vs Supply Voltage

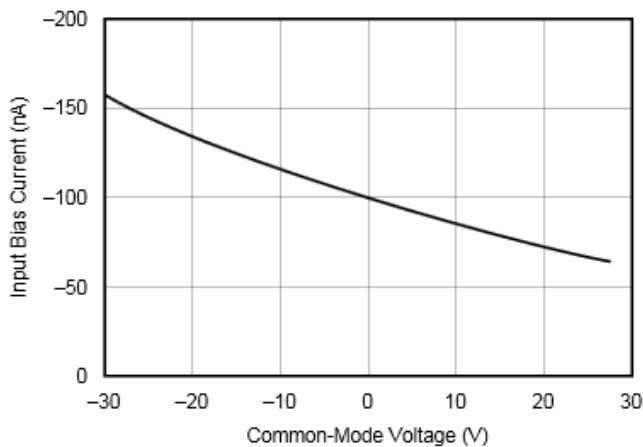


Figure 5. Input Bias Current vs Common-Mode Voltage

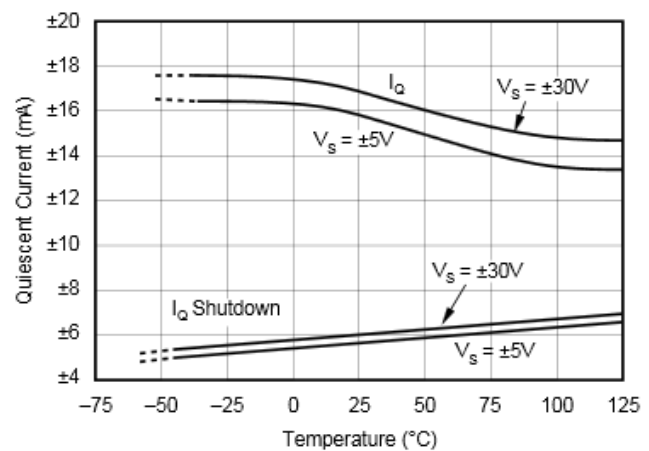


Figure 6. Quiescent Current vs Temperature

## Typical Characteristics (continued)

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

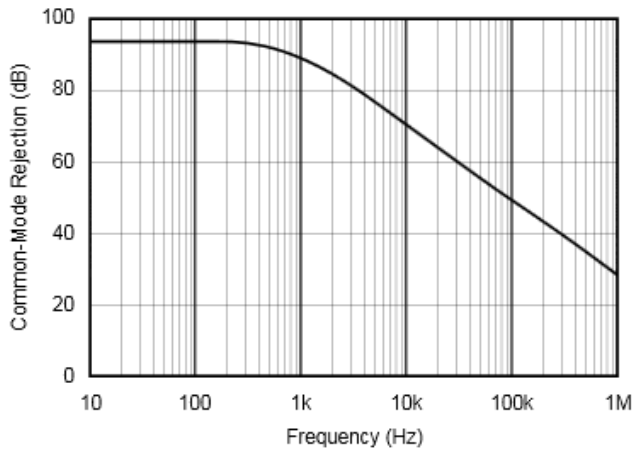


Figure 7. Common-Mode Rejection vs Frequency

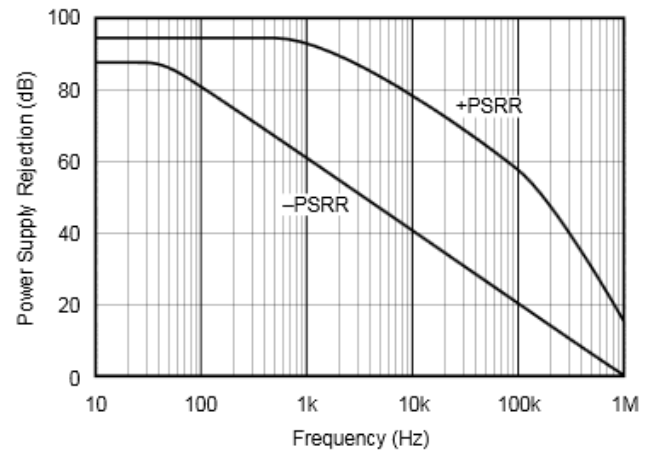


Figure 8. Power-Supply Rejection vs Frequency

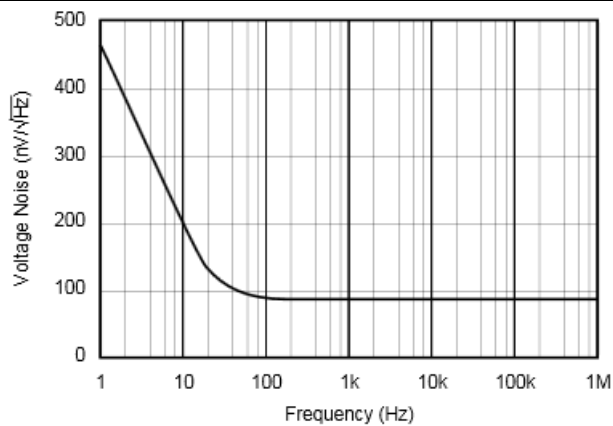


Figure 9. Voltage Noise Density vs Frequency

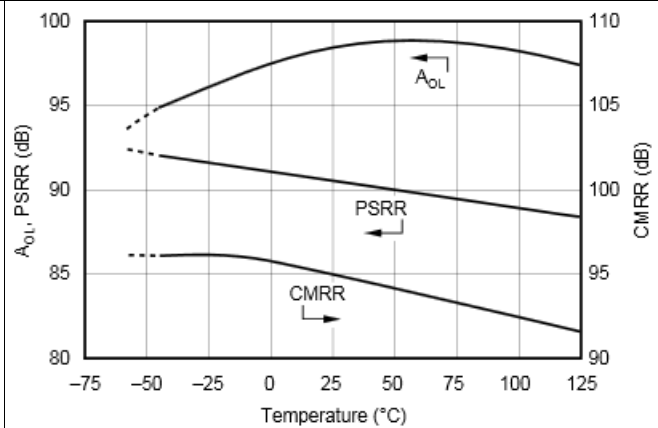


Figure 10. Open-loop Gain, Common-Mode Rejection, and Power-Supply Rejection vs Temperature

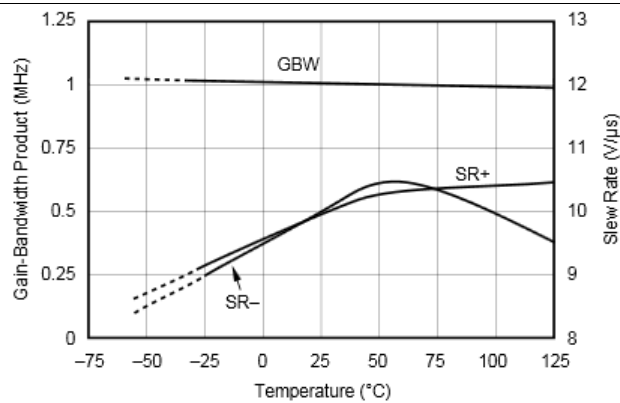


Figure 11. Gain-Bandwidth Product and Slew Rate vs Temperature

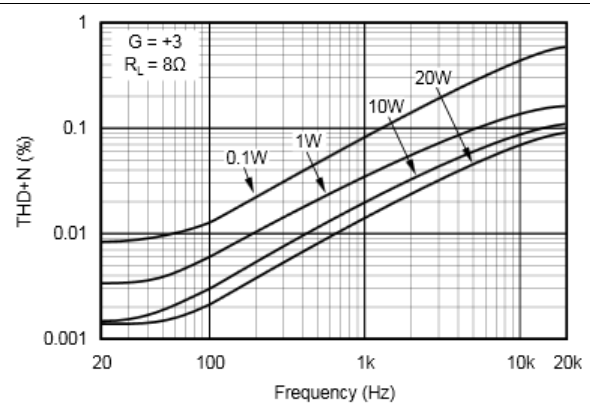


Figure 12. Total Harmonic Distortion+Noise vs Frequency

## Typical Characteristics (continued)

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

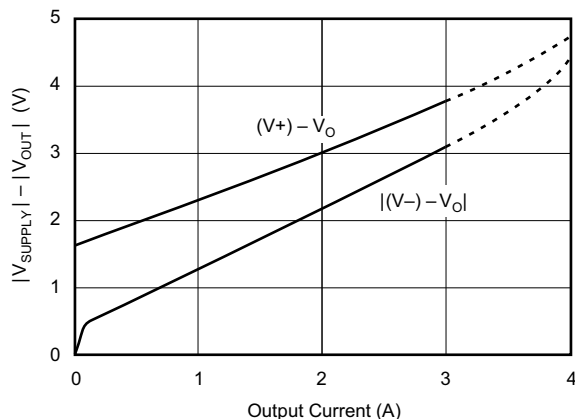


Figure 13. Output Voltage Swing vs Output Current

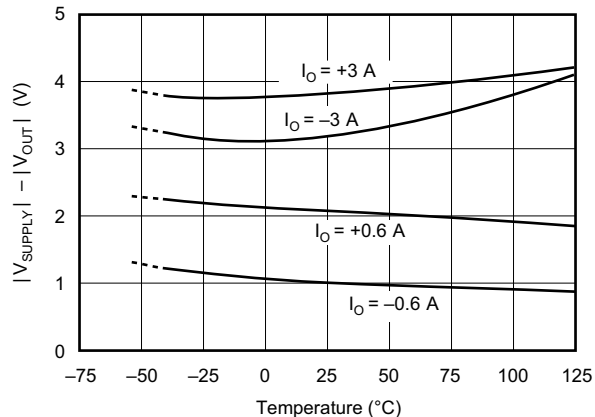


Figure 14. Output Voltage Swing vs Temperature

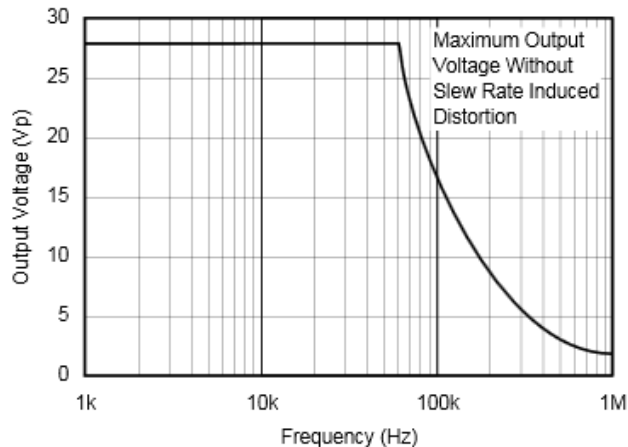


Figure 15. Maximum Output Voltage Swing vs Frequency

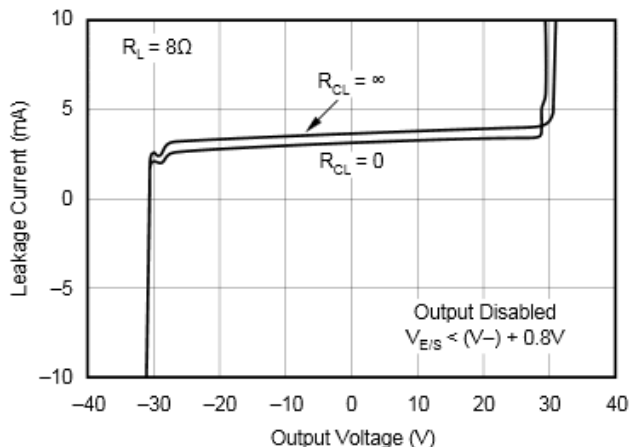


Figure 16. Output Leakage Current vs Applied Output Voltage

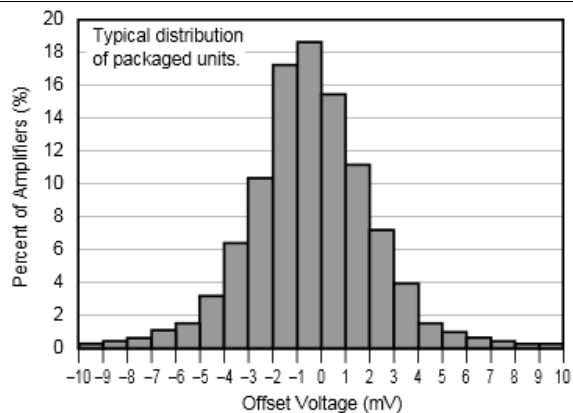


Figure 17. Offset Voltage Production Distribution

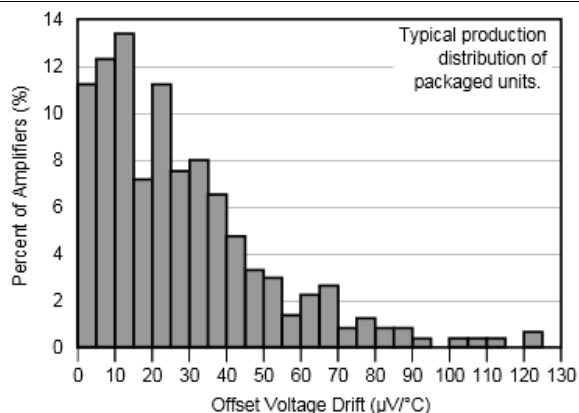
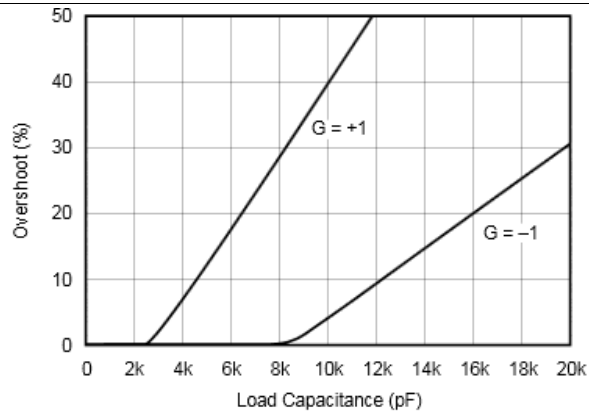


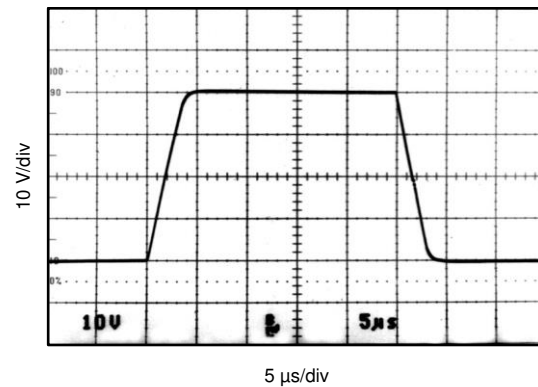
Figure 18. Offset Voltage Drift Production Distribution

## Typical Characteristics (continued)

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

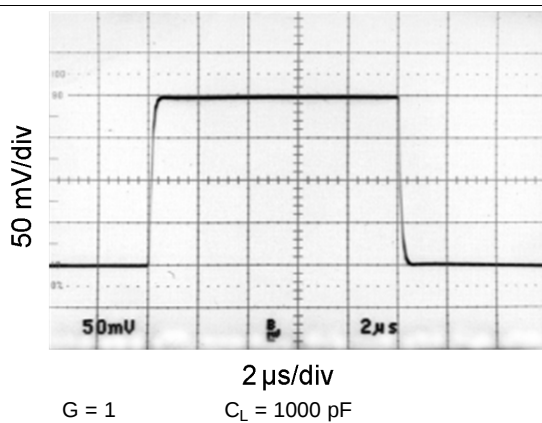


**Figure 19. Small-Signal Overshoot vs Load Capacitance**



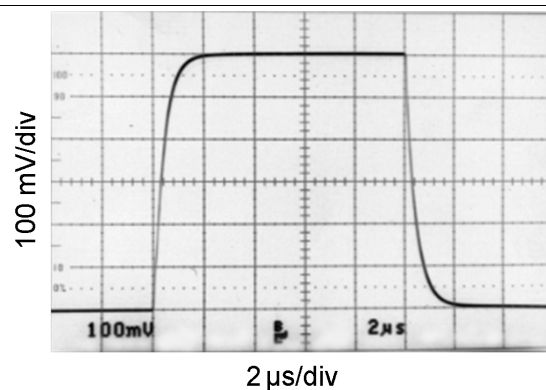
$G = 3$        $C_L = 1000 \text{ pF}$ ,       $R_L = 8 \Omega$

**Figure 20. Large-Signal Step Response**



$G = 1$        $C_L = 1000 \text{ pF}$

**Figure 21. Small-Signal Step Response**



$G = 3$        $C_L = 1000 \text{ pF}$

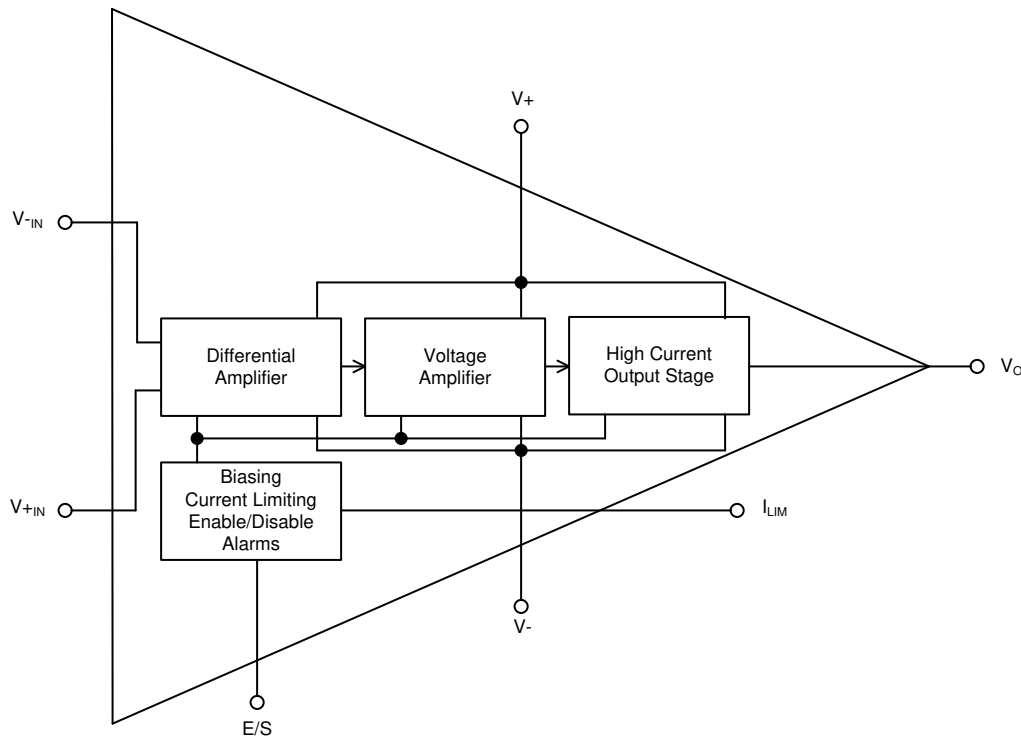
**Figure 22. Small-Signal Step Response**

## 7 Detailed Description

### 7.1 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](#)).

### 7.2 Functional Block Diagram



### 7.3 Feature Description

#### 7.3.1 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- $\mu$ A to 330- $\mu$ 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  $\mu$ A to 330  $\mu$ 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)

### 7.3.2 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<sub>-</sub> may be required for noisy applications.

### 7.3.3 Thermal Shutdown Status

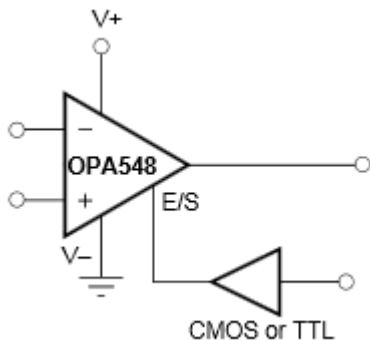
Internal thermal shutdown circuitry shuts down the output when the die temperature reaches approximately 160°C, resetting when the die has cooled to 140°C. The E/S pin can be monitored to determine if shutdown has occurred. During normal operation the voltage on the E/S pin is typically 3.5 V more than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

## 7.4 Device Functional Modes

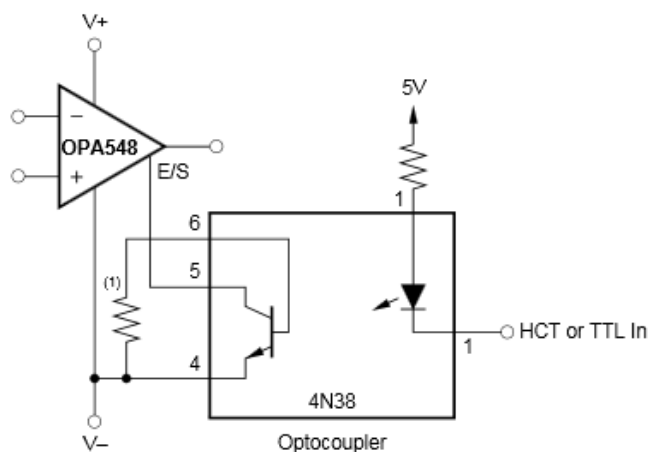
### 7.4.1 Output Disable

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  $\mu$ 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<sub>-</sub>) + 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**

## 8 Application and Implementation

### NOTE

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

### 8.1 Application Information

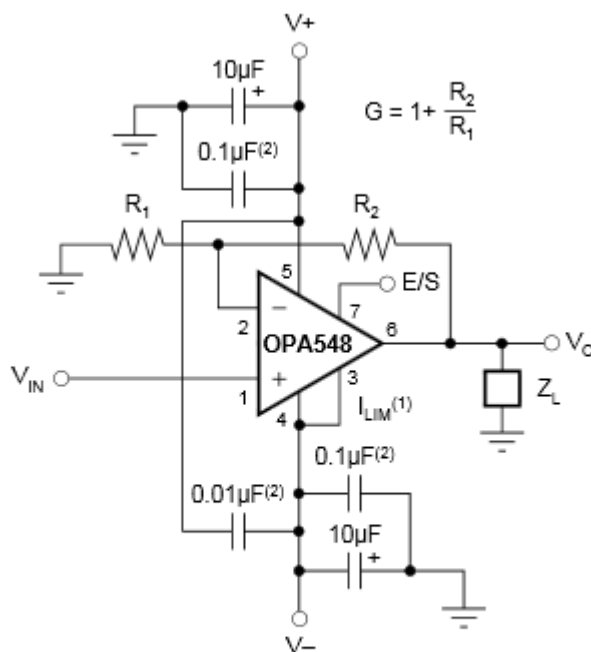
The OPA548 is specified for operation from 8 V to 60 V ( $\pm 4$  V to  $\pm 30$  V). Specifications apply over the  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  temperature range while the device operates from  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ . Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in [Typical Characteristics](#).

### 8.2 Typical Applications

#### 8.2.1 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 44](#), using a ceramic and tantalum type in parallel is recommended. In addition, we recommend a  $0.01\text{-}\mu\text{F}$  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.

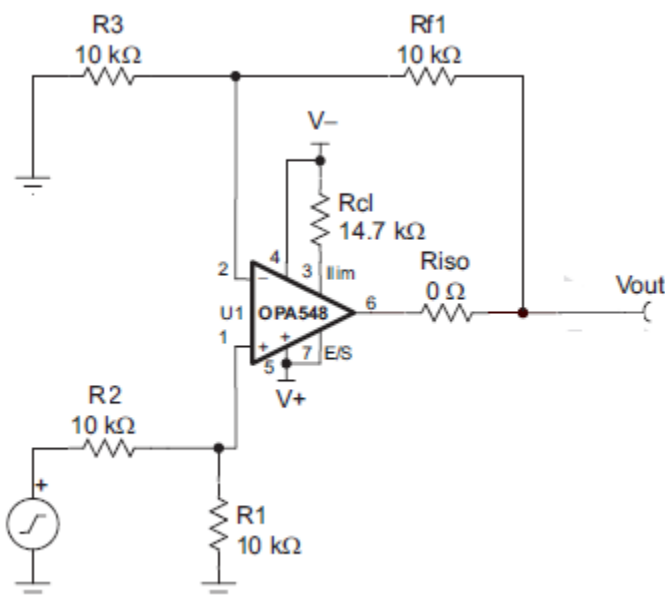
**Figure 25. Basic Circuit Connections Example**

## Typical Applications (continued)

### 8.2.1.1 Design Requirements

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

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



**Figure 26. Noninverting Amplifier Configuration Schematic**

### 8.2.1.2 Detailed Design Procedure

#### 8.2.1.2.1 Power Supply Requirements

Select the power supply based on the requirement to achieve a  $\pm 10$ -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.

#### 8.2.1.2.2 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-k $\Omega$  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.

## Typical Applications (continued)

### 8.2.1.2.3 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 Ilim pin, or a DAC can be used to set the current limit. For this circuit a 14.7-k $\Omega$  resistor (Rcl) limits the output current to approximately 2.5 A.

### 8.2.1.2.4 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- $\Omega$  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.

### 8.2.1.2.5 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  $R_{\theta HA} < 2.5^{\circ}\text{C/W}$ , such as an Aavid Thermalloy 530002B02500G.

### 8.2.1.3 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- $\Omega$  load.

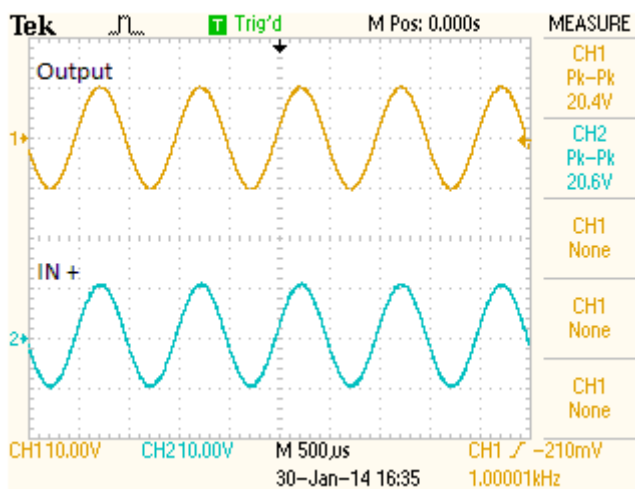


Figure 27. Noninverting Operation, Dual-Supply Waveforms

## Typical Applications (continued)

### 8.2.2 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.

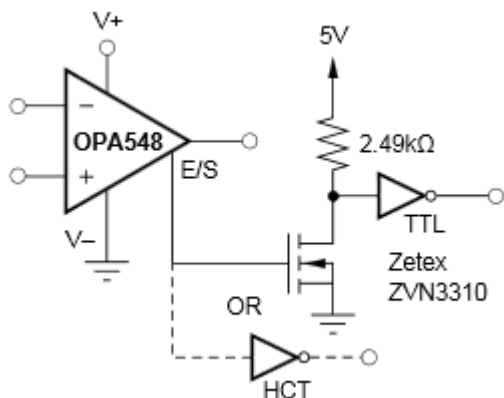


Figure 28. Thermal Shutdown Status With a Single-Supply

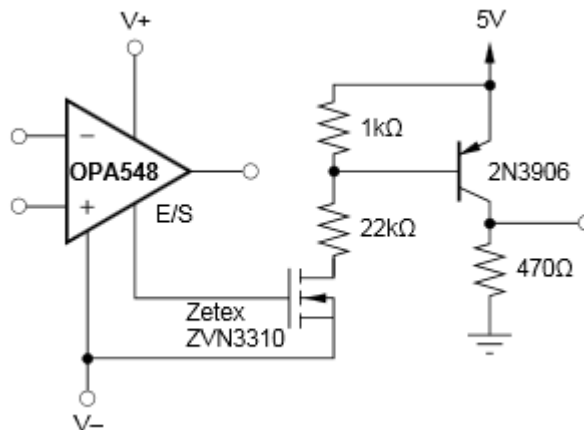


Figure 29. Thermal Shutdown Status With Dual-Supplies

#### 8.2.2.1 Design Requirements

See the previous [Design Requirements](#).

#### 8.2.2.2 Detailed Design Procedure

##### 8.2.2.2.1 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.

## Typical Applications (continued)

### 8.2.3 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.

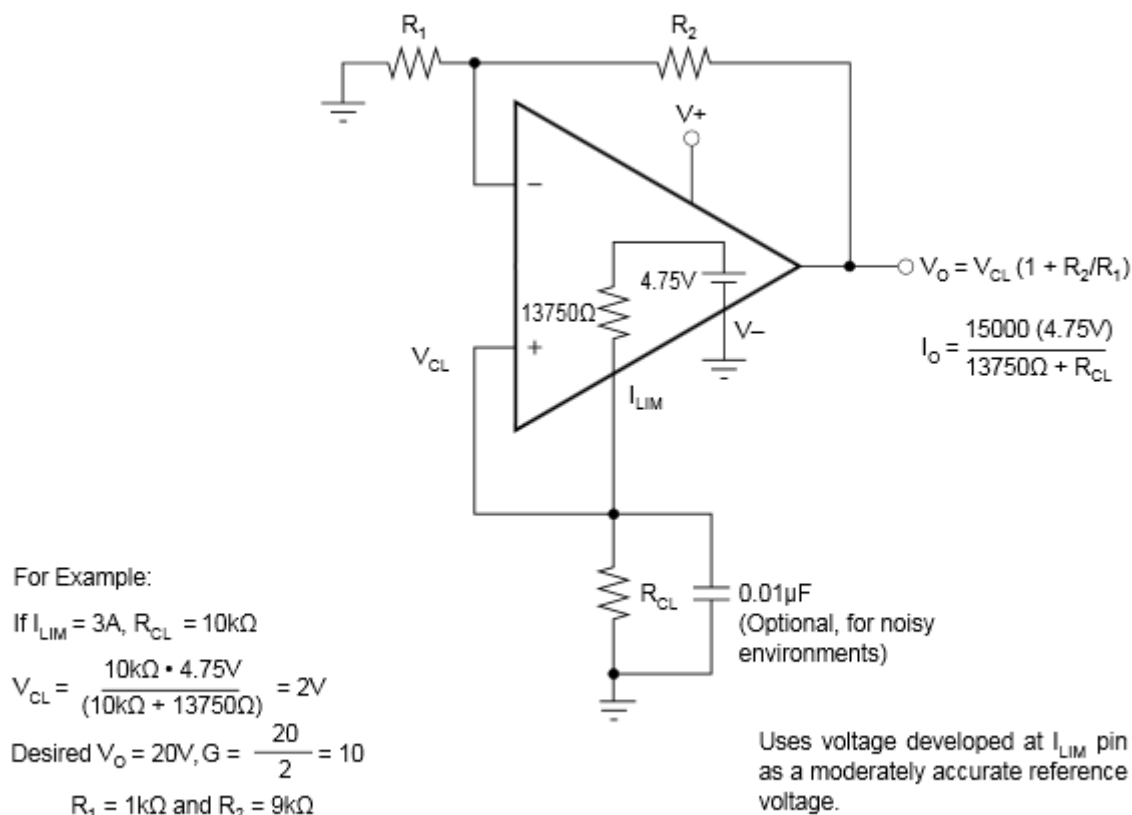


Figure 30. Voltage Source Schematic

## Typical Applications (continued)

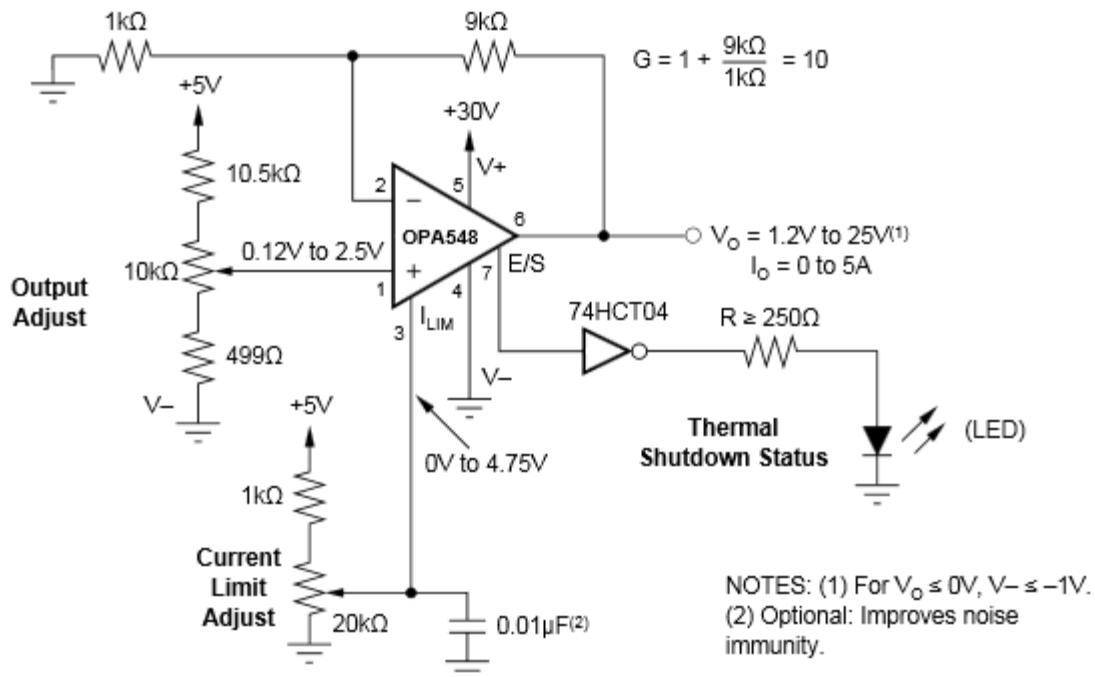
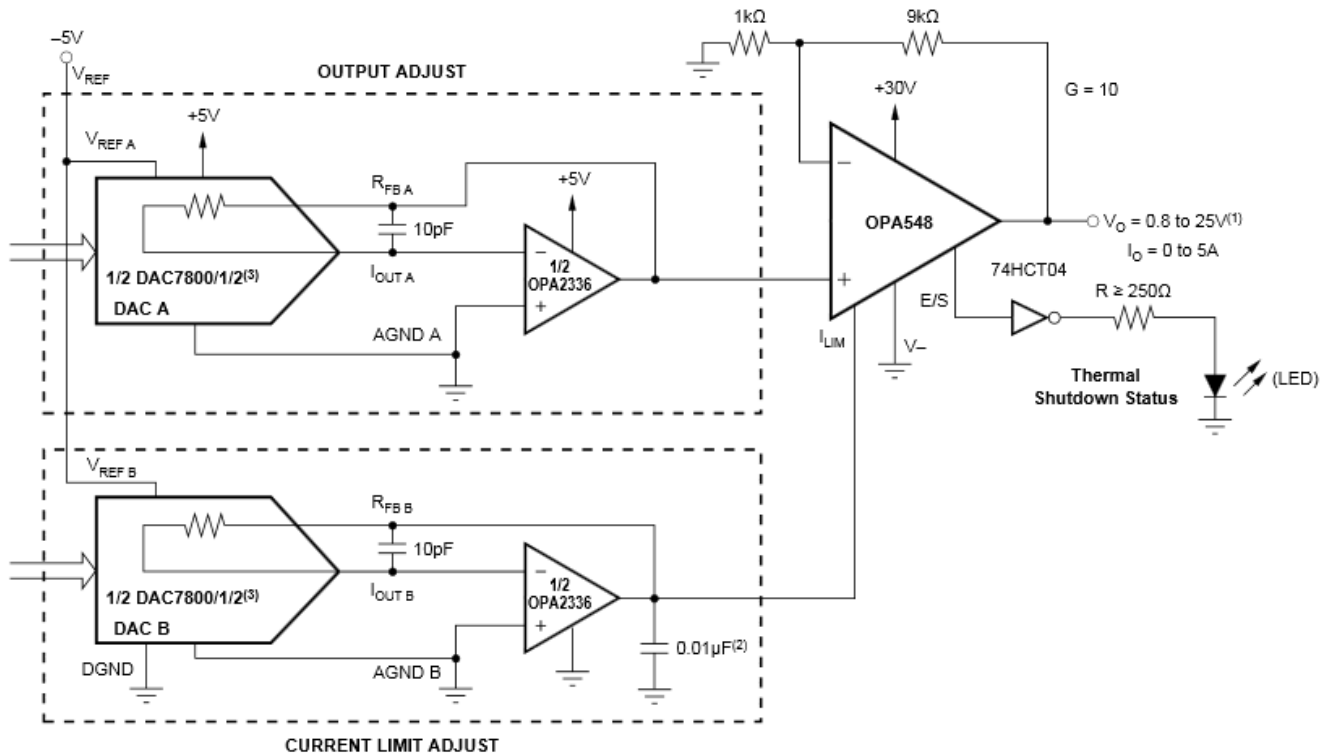


Figure 31. Resistor-Controlled Programmable Power Supply Schematic

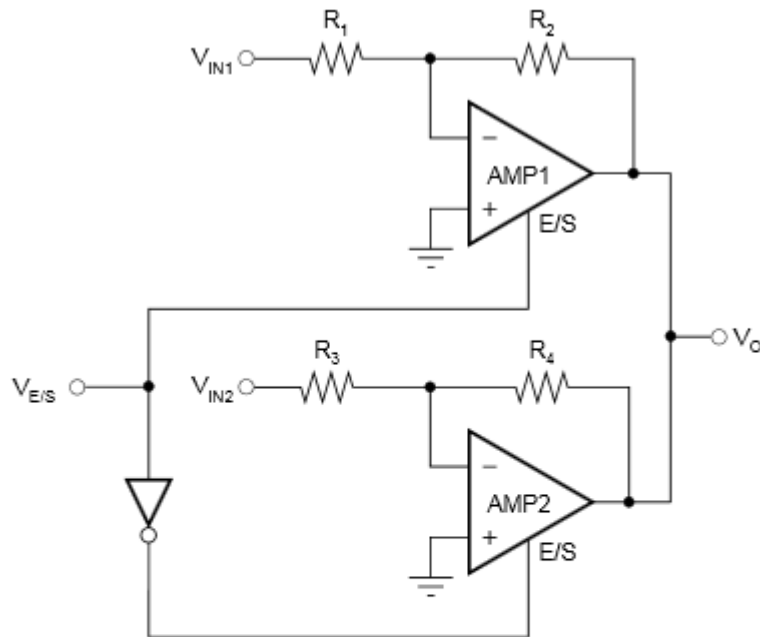
## Typical Applications (continued)



NOTES: (1) For  $V_O \leq 0V$ ,  $V_- \leq -1V$ . (2) Optional, improves noise immunity. (3) Chose 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

### 8.3 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

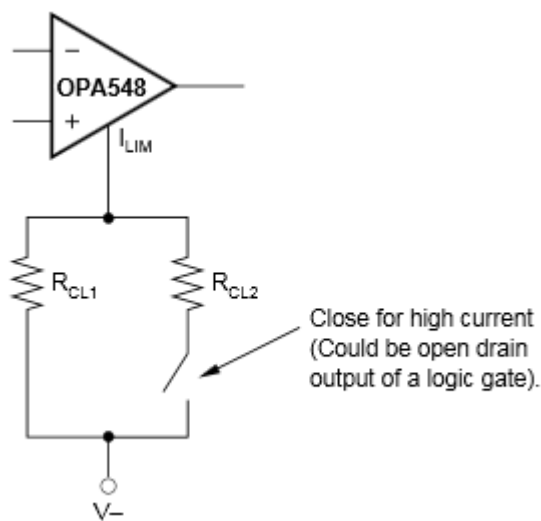
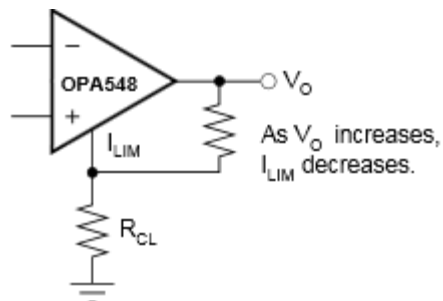
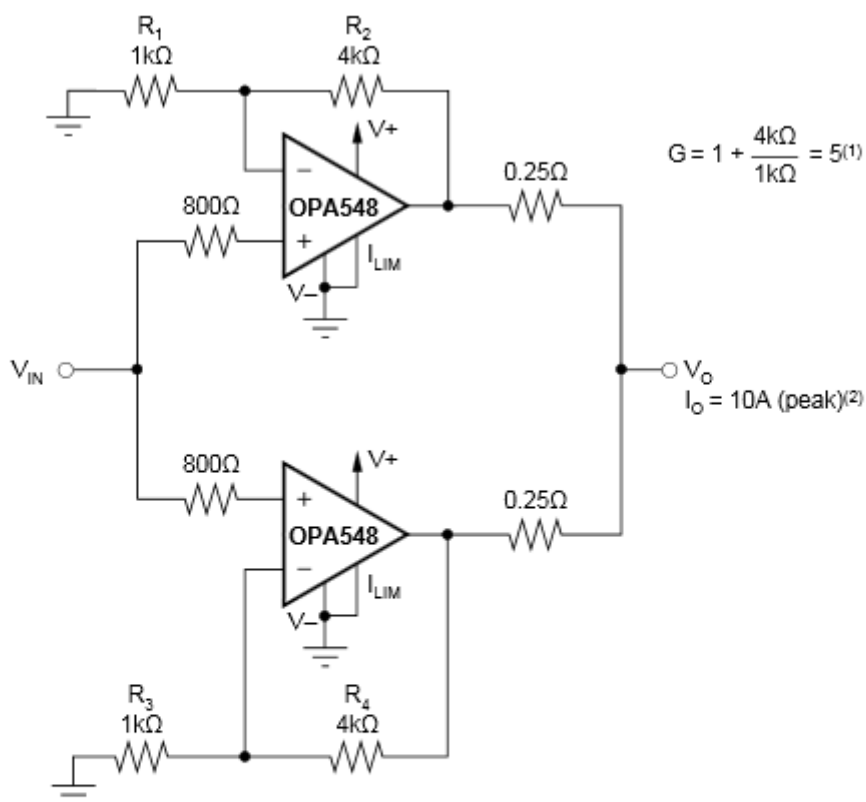


Figure 34. Multiple Current Limit Values Schematic

## System Examples (continued)



**Figure 35. Single Quadrant V × 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**

## 9 Power Supply Recommendations

The OPA548 operates from single (8 V to 60 V) or dual ( $\pm 4$  V to  $\pm 30$  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.

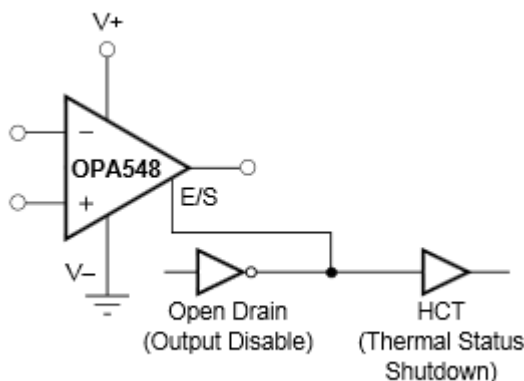
### 9.1 Output Stage Compensation

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.

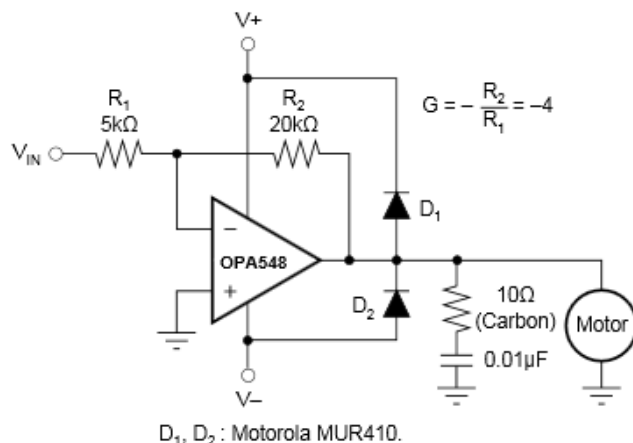
A snubber circuit may also enhance stability when driving large capacitive loads ( $> 1000$  pF) or inductive loads (motors, loads separated from the amplifier by long cables). Typically  $3\ \Omega$  to  $10\ \Omega$  in series with  $0.01\ \mu\text{F}$  to  $0.1\ \mu\text{F}$  is adequate. Some variations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

### 9.2 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.

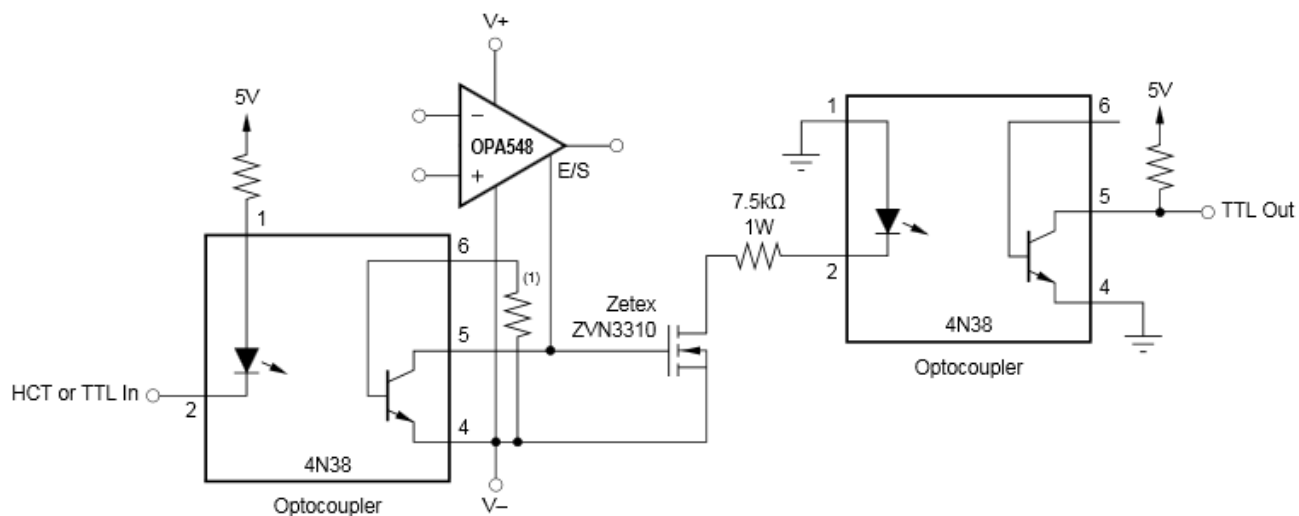


**Figure 37. Output Disable and Thermal Shutdown Status With a Single Supply**



**Figure 38. Motor Drive Circuit**

## Output Protection (continued)



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

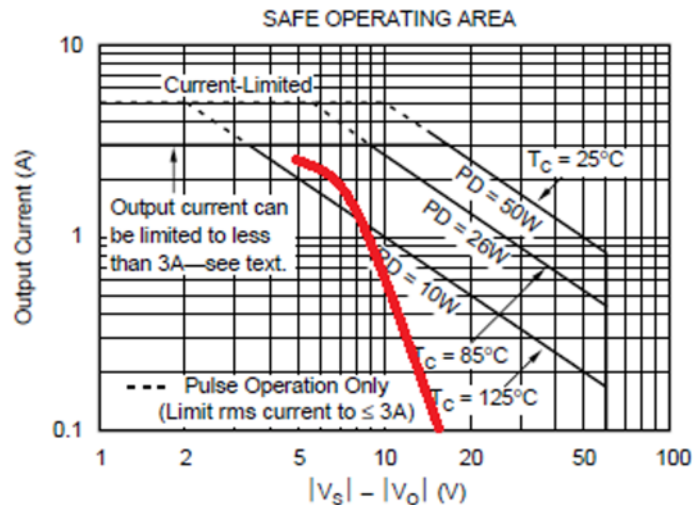
**Figure 39. Output Disable and Thermal Shutdown Status With Dual Supplies**

## 10 Layout

### 10.1 Layout Guidelines

#### 10.1.1 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**

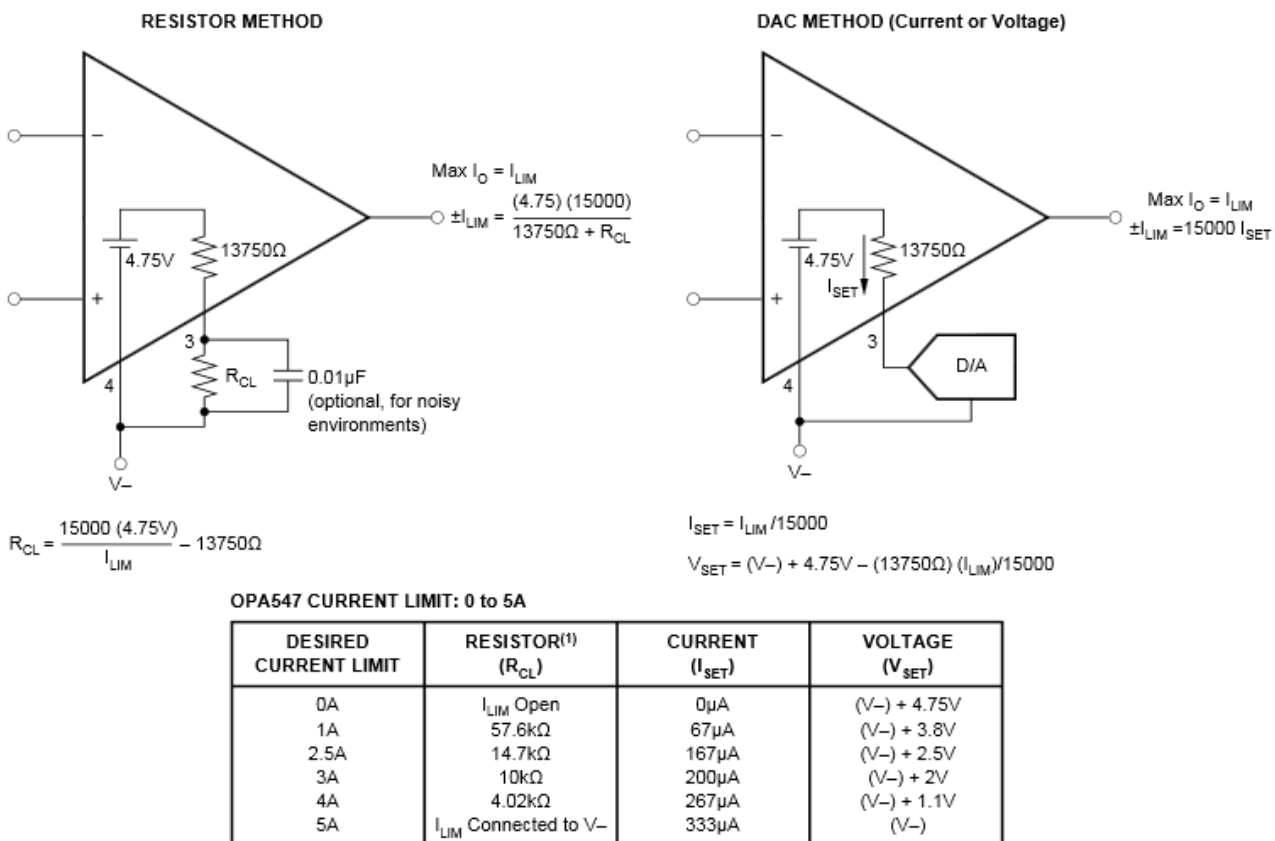
The safe output current decreases as  $V_S - V_O$  increases. Output short circuits are a very demanding case for SOA. A short-circuit to ground forces the full power-supply voltage ( $V_+$  or  $V_-$ ) across the conducting transistor. Increasing the case temperature reduces the safe output current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

## Layout Guidelines (continued)

### 10.1.2 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 42). 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 43 for typical thermal resistance from junction-to-ambient as a function of the copper area.



NOTE: (1) Resistors are nearest standard 1% values.

Figure 41. Adjustable Current Limit

## Layout Guidelines (continued)

### 10.1.3 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.

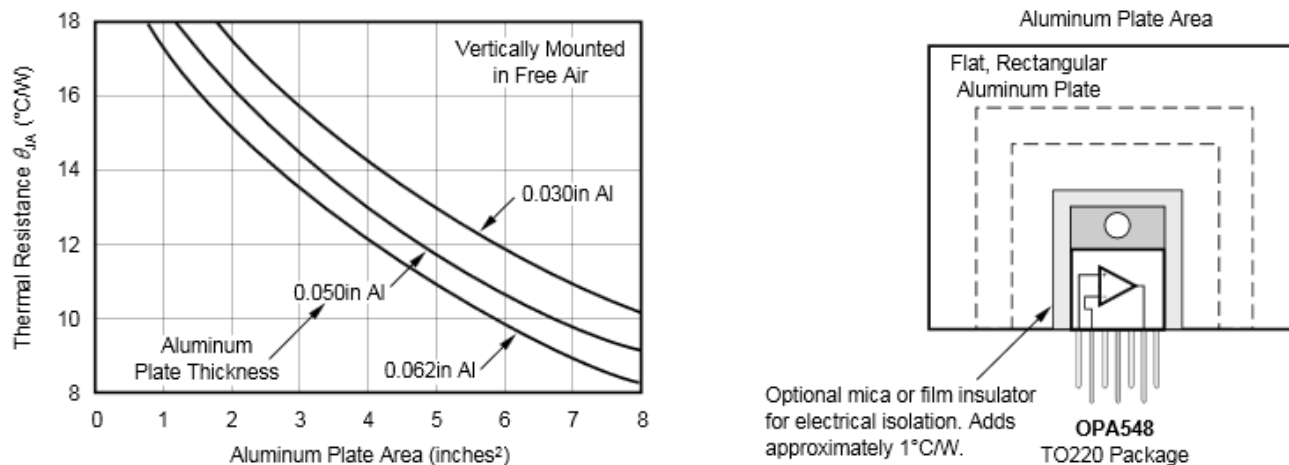


Figure 42. TO-220 Thermal Resistance vs Aluminum Plate Area

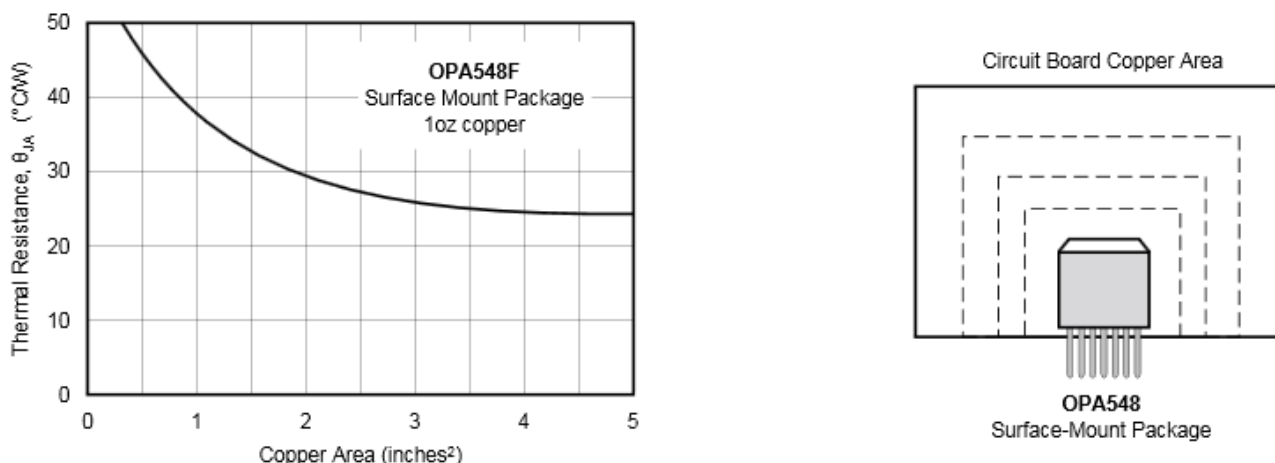


Figure 43. DDPAK Thermal Resistance vs Circuit Board Copper Area

### 10.1.4 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.

## Layout Guidelines (continued)

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.

### 10.1.5 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:

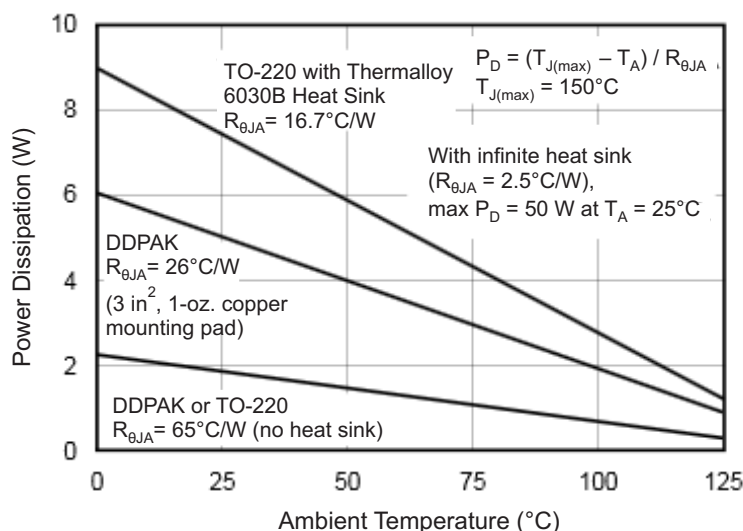
$$T_J = T_A + P_D R_{\theta JA}$$

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 44 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 44. Maximum Power Dissipation vs Ambient Temperature**

## Layout Guidelines (continued)

### 10.1.5.1 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  $R_{\theta HA}$ :

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

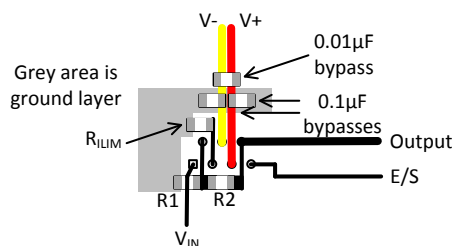
$$\theta_{HA} = \frac{125^\circ\text{C} - 40^\circ\text{C}}{5\text{W}} - (2.5^\circ\text{C/W} + 1^\circ\text{C/W}) = 13.5^\circ\text{C/W} \quad (4)$$

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 × 5 W). For example, at 5-W Thermalloy model number 6030B has a heat sink temperature rise of 66°C more than ambient ( $R_{\theta HA} = 66^\circ\text{C} / 5\text{W} = 13.2^\circ\text{C/W}$ ), which is less than the 67.5°C required in this example. Figure 44 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 manufactures 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 maintain proper thermal protection.

## 10.2 Layout Example



**Figure 45. Recommended Layout Example**

## 11 デバイスおよびドキュメントのサポート

### 11.1 デバイス・サポート

#### 11.1.1 デベロッパー・ネットワークの製品に関する免責事項

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### 11.2 ドキュメントのサポート

#### 11.2.1 関連資料

テキサス・インスツルメンツ『[HEAT SINKING — TO-3 THERMAL MODEL](#)』アプリケーション広報 (英語)

#### 11.3 ドキュメントの更新通知を受け取る方法

ドキュメントの更新についての通知を受け取るには、[ti.com](#)のデバイス製品フォルダを開いてください。右上の「アラートを受け取る」をクリックして登録すると、変更されたすべての製品情報に関するダイジェストを毎週受け取れます。変更の詳細については、修正されたドキュメントに含まれている改訂履歴をご覧ください。

### 11.4 サポート・リソース

[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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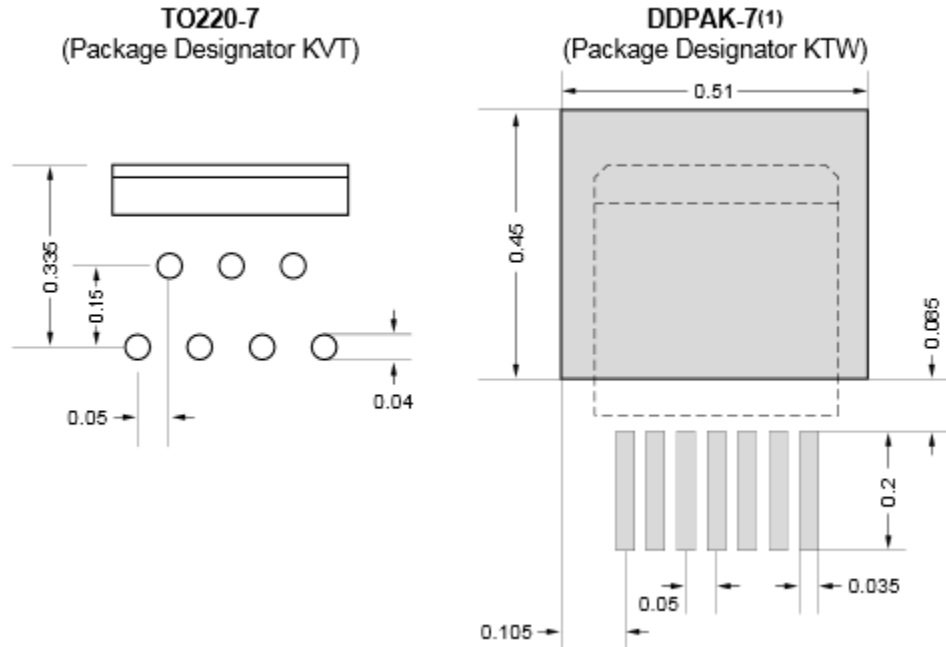
### 11.7 Glossary

[SLYZ022](#) — *TI Glossary*.

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

## 12 メカニカル、パッケージ、および注文情報

以降のページには、メカニカル、パッケージ、および注文に関する情報が記載されています。この情報は、そのデバイスについて利用可能な最新のデータです。このデータは予告なく変更されることがあり、ドキュメントが改訂される場合もあります。本データシートのブラウザ版を使用されている場合は、画面左側の説明をご覧ください。



- (1) 熱性能を向上するには、フットプリントの面積を増やします。Figure 43 を参照してください。
- (2) 平均寸法はインチ単位です。公差とパッケージ詳細図については、機械的図面または [www.ti.com](http://www.ti.com) を参照してください。

**図 46. TO-220 と DDPACK のハンダのフットプリント**

## PACKAGING INFORMATION

| Orderable Device | Status<br>(1) | Package Type     | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2) | Lead finish/<br>Ball material<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|------------------|--------------------|------|----------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|-------------------------|
| OPA548F/500      | ACTIVE        | DDPAK/<br>TO-263 | KTW                | 7    | 500            | RoHS & Green    | Call TI   SN                         | Level-2-260C-1 YEAR  | -40 to 85    | OPA548F                 | <a href="#">Samples</a> |
| OPA548FKTWT      | ACTIVE        | DDPAK/<br>TO-263 | KTW                | 7    | 250            | RoHS & Green    | Call TI   SN                         | Level-2-260C-1 YEAR  | -40 to 85    | OPA548F                 | <a href="#">Samples</a> |
| OPA548T          | ACTIVE        | TO-220           | KVT                | 7    | 50             | RoHS & Green    | Call TI   SN                         | N / A for Pkg Type   | -40 to 85    | OPA548T                 | <a href="#">Samples</a> |
| OPA548T-1        | ACTIVE        | TO-220           | KC                 | 7    | 50             | RoHS & Green    | Call TI   SN                         | N / A for Pkg Type   | -40 to 85    | OPA548T                 | <a href="#">Samples</a> |
| OPA548TG3        | LIFEBUY       | TO-220           | KVT                | 7    | 50             | RoHS & Green    | SN                                   | N / A for Pkg Type   | -40 to 85    | OPA548T                 |                         |

(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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## TUBE

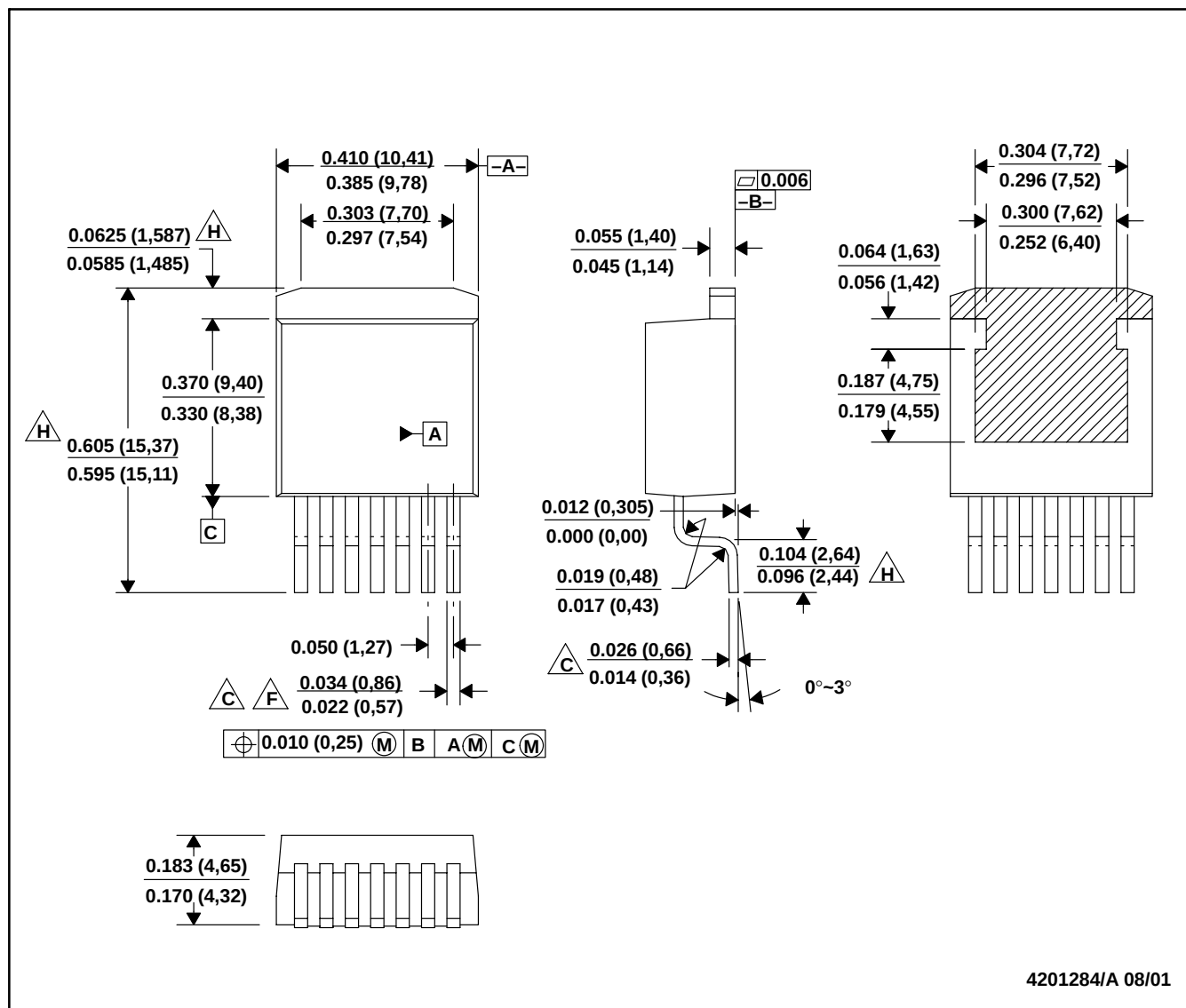


\*All dimensions are nominal

| Device    | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (μm) | B (mm) |
|-----------|--------------|--------------|------|-----|--------|--------|--------|--------|
| OPA548T   | KVT          | TO-220       | 7    | 50  | 532.13 | 34.54  | 13340  | NA     |
| OPA548T-1 | KC           | TO-220       | 7    | 50  | 532.13 | 34.54  | 13340  | NA     |
| OPA548TG3 | KVT          | TO-220       | 7    | 50  | 532.13 | 34.54  | 13340  | NA     |

## KTW (R-PSFM-G7)

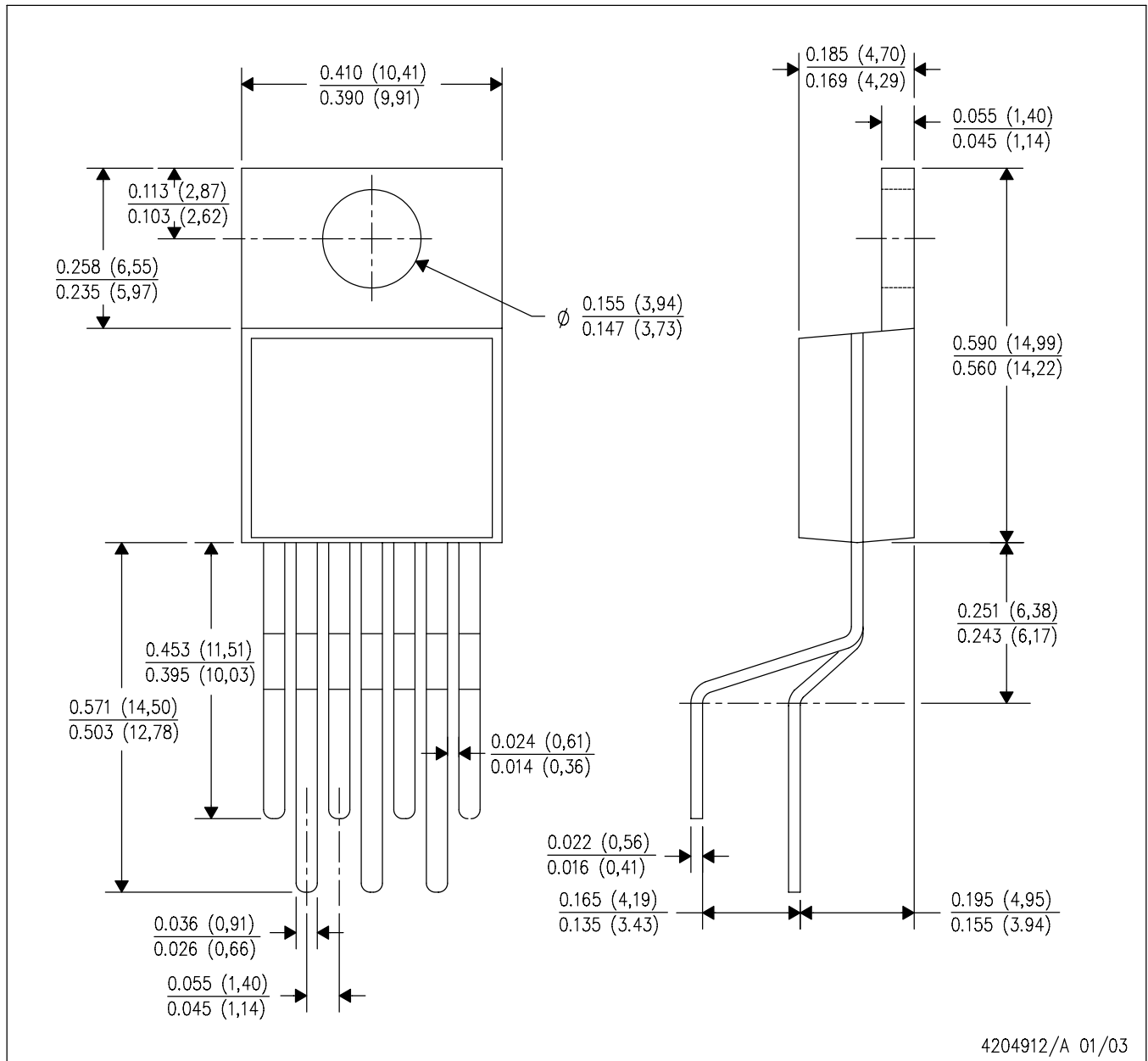
## PLASTIC FLANGE-MOUNT



- 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)

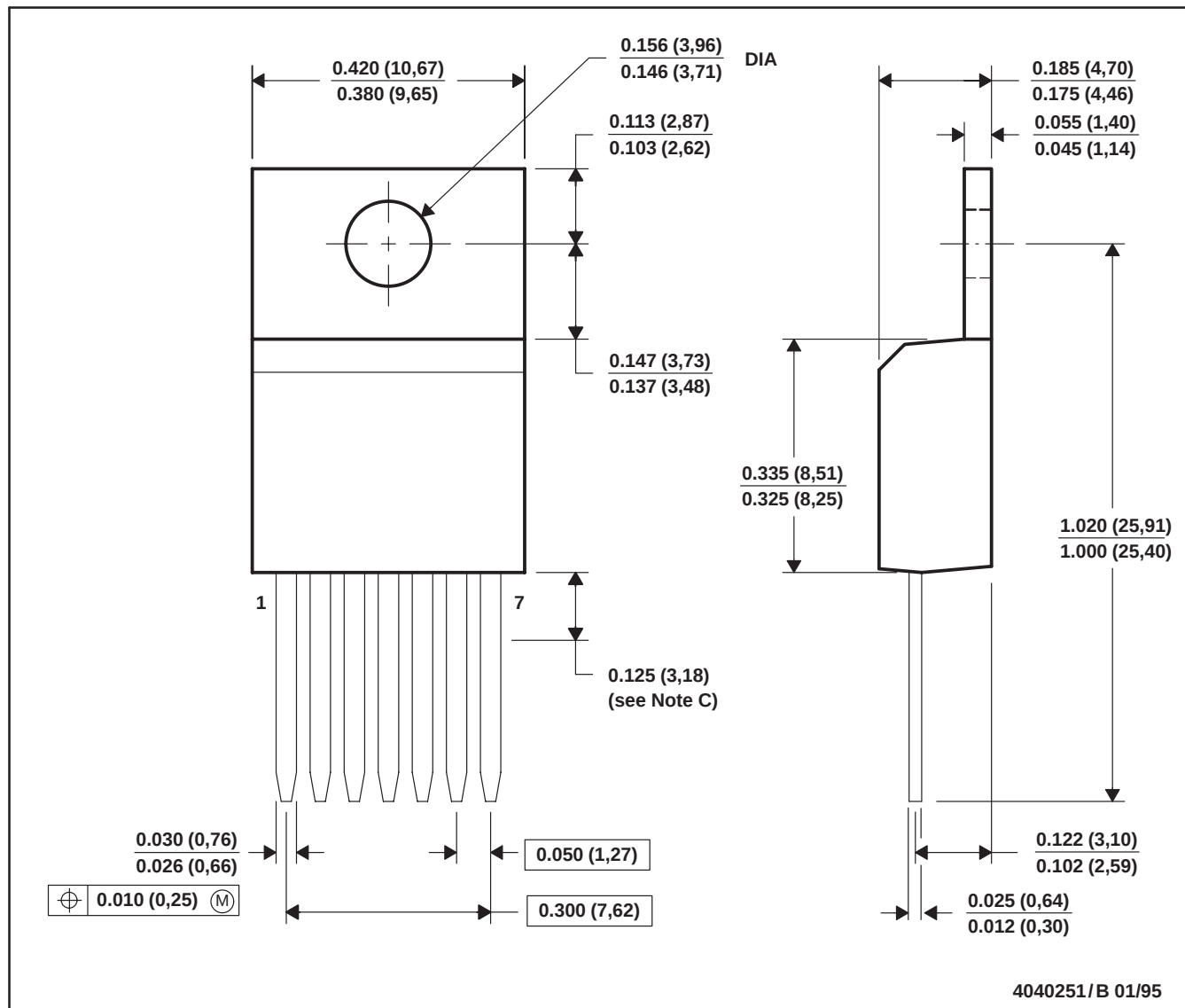
PLASTIC FLANGE MOUNT PACKAGE



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

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