

## LM10-MIL Operational Amplifier and Voltage Reference

### 1 Features

- Input Offset Voltage: 2 mV (Maximum)
- Input Offset Current: 0.7 nA (Maximum)
- Input Bias Current: 20 nA (Maximum)
- Reference Regulation: 0.1% (Maximum)
- Offset Voltage Drift: 2  $\mu\text{V}/^\circ\text{C}$
- Reference Drift: 0.002%/°C

### 2 Applications

- Remote Amplifiers
- Battery-Level Indicators
- Thermocouple Transmitters
- Voltage and Current regulators

### 3 Description

The LM10-MIL is a monolithic linear IC consisting of a precision reference, an adjustable reference buffer, and an independent, high-quality operational amplifier.

The unit can operate from a total supply voltage as low as 1.1 V or as high as 40 V, drawing only 270  $\mu\text{A}$ . A complementary output stage swings within 15 mV of the supply terminals or will deliver  $\pm 20\text{-mA}$  output current with  $\pm 0.4\text{-V}$  saturation. Reference output can be as low as 200 mV.

The circuit is recommended for portable equipment and is completely specified for operation from a single power cell. In contrast, high output-drive capability, both voltage and current, along with thermal overload protection, suggest it in demanding general-purpose applications.

The device is capable of operating in a floating mode, independent of fixed supplies. It can function as a remote comparator, signal conditioner, SCR controller or transmitter for analog signals, delivering the processed signal on the same line used to supply power. It is also suited for operation in a wide range of voltage and current regulator applications, from low voltages to several hundred volts, providing greater precision than existing ICs.

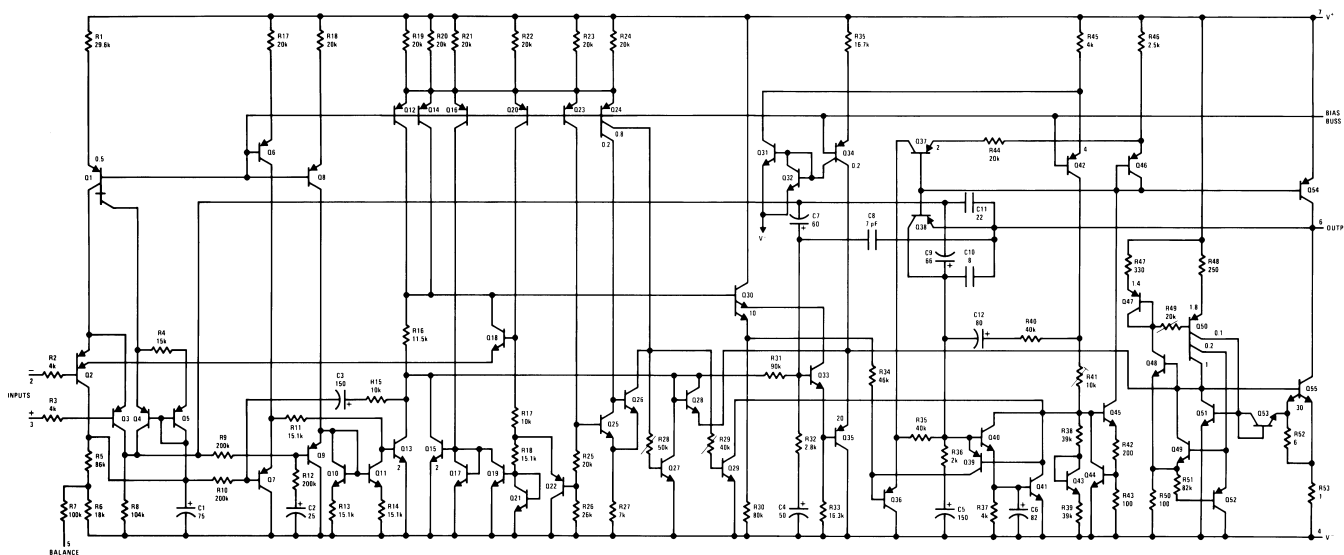
This series is available in the three standard temperature ranges, with the commercial part having relaxed limits. In addition, a low-voltage specification (suffix L) is available in the limited temperature ranges at a cost savings.

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

| PART NUMBER | PACKAGE   | BODY SIZE (NOM)     |
|-------------|-----------|---------------------|
| LM10-MIL    | SOIC (14) | 8.992 mm × 7.498 mm |
|             | SDIP (8)  | 8.255 mm × 8.255 mm |
|             | PDIP (8)  | 9.81 mm × 6.35 mm   |

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

#### Operational Amplifier Schematic



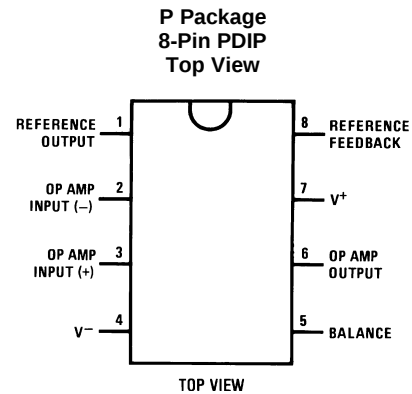
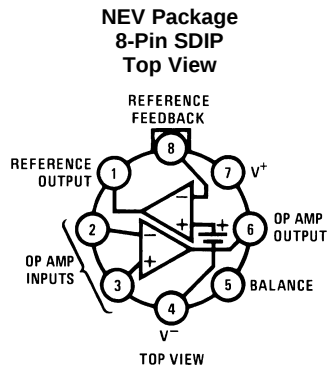
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## 4 Revision History

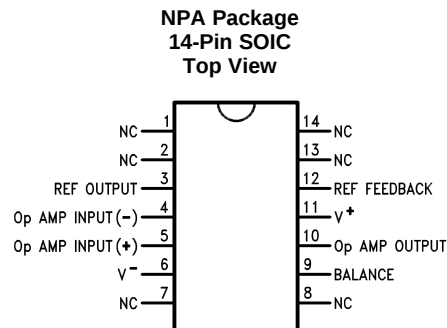
| DATE      | REVISION | NOTES           |
|-----------|----------|-----------------|
| June 2017 | *        | Initial Release |

## 5 Pin Configuration and Functions



**Pin Functions — 8-Pin SDIP or PDIP**

| PIN                |     | I/O | DESCRIPTION                                 |
|--------------------|-----|-----|---------------------------------------------|
| NAME               | NO. |     |                                             |
| Balance            | 5   | I   | Used for offset nulling                     |
| Op Amp Input (+)   | 3   | I   | Noninverting input of operational amplifier |
| Op Amp Input (-)   | 2   | I   | Inverting input of operational amplifier    |
| Op Amp Output      | 6   | O   | Output terminal of operational amplifier    |
| Reference Feedback | 8   | I   | Feedback terminal of reference              |
| Reference Output   | 1   | O   | Output terminal of reference                |
| V+                 | 7   | I   | Positive supply voltage                     |
| V-                 | 4   | I   | Negative supply voltage                     |



**Pin Functions — 14-Pin SOIC**

| PIN                |                    | I/O | DESCRIPTION                                 |
|--------------------|--------------------|-----|---------------------------------------------|
| NAME               | NO.                |     |                                             |
| Balance            | 9                  | I   | Used for offset nulling                     |
| NC                 | 1, 2, 7, 8, 14, 13 | —   | No connection                               |
| Op Amp Input (-)   | 4                  | I   | Inverting input of operational amplifier    |
| Op Amp Input (+)   | 5                  | I   | Noninverting input of operational amplifier |
| Op Amp Output      | 10                 | O   | Output terminal of operational amplifier    |
| Reference Feedback | 12                 | I   | Feedback terminal of reference              |
| Reference Output   | 3                  | O   | Output terminal of reference                |
| V+                 | 11                 | I   | Positive supply voltage                     |
| V-                 | 6                  | I   | Negative supply voltage                     |

## 6 Specifications

### 6.1 Absolute Maximum Ratings

See <sup>(1)(2)(3)</sup>

|                                              |     |                          | MIN                | MAX | UNIT |
|----------------------------------------------|-----|--------------------------|--------------------|-----|------|
| Total supply voltage                         |     |                          |                    | 45  | V    |
| Differential input voltage <sup>(4)</sup>    |     |                          |                    | ±40 | V    |
| Power dissipation <sup>(5)</sup>             |     |                          | Internally limited |     |      |
| Output short-circuit duration <sup>(6)</sup> |     |                          | Continuous         |     |      |
| Lead temperature                             | TO  | Soldering (10 seconds)   |                    | 300 | °C   |
|                                              | DIP | Soldering (10 seconds)   |                    | 260 | °C   |
|                                              |     | Vapor phase (60 seconds) |                    | 215 | °C   |
|                                              |     | Infrared (15 seconds)    |                    | 220 | °C   |
| Maximum junction temperature                 |     |                          |                    | 150 | °C   |
| Storage temperature, T <sub>stg</sub>        |     |                          | −55                | 150 | °C   |

- (1) Refer to RETS10X for LM10H military specifications.
- (2) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
- (4) The Input voltage can exceed the supply voltages provided that the voltage from the input to any other terminal does not exceed the maximum differential input voltage and excess dissipation is accounted for when  $V_{IN} < V^-$ .
- (5) The maximum, operating-junction temperature is 150°C for the LM10-MIL. At elevated temperatures, devices must be derated based on package thermal resistance.
- (6) Internal thermal limiting prevents excessive heating that could result in sudden failure, but the IC can be subjected to accelerated stress with a shorted output and worst-case conditions.

### 6.2 Recommended Operating Conditions

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

|                  |                                                                  | MIN               | NOM | MAX                      | UNIT |
|------------------|------------------------------------------------------------------|-------------------|-----|--------------------------|------|
| V <sub>S</sub>   | Supply input voltage range (V <sup>-</sup> ) – (V <sup>+</sup> ) | 1.2               |     | 40                       | V    |
| V <sub>CM</sub>  | Common-mode voltage                                              | (V <sup>-</sup> ) |     | (V <sup>+</sup> ) – 0.85 | V    |
| V <sub>REF</sub> | Reference voltage                                                |                   | 0.2 |                          | V    |
| I <sub>REF</sub> | Reference current                                                | 0                 |     | 1                        | mA   |

### 6.3 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                           | LM10-MIL   |            |          | UNIT |
|-------------------------------|-------------------------------------------|------------|------------|----------|------|
|                               |                                           | NEV (SDIP) | NPA (SOIC) | P (PDIP) |      |
|                               |                                           | 8 PINS     | 14 PINS    | 8 PINS   |      |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance    | 150        | 90         | 87       | °C/W |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance | 45         | —          | —        | °C/W |

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

## 6.4 Electrical Characteristics

 $T_J = 25^\circ\text{C}$  unless otherwise specified<sup>(1)</sup>

| PARAMETER                           | TEST CONDITIONS                                                                                                                                        | MIN | TYP   | MAX   | UNIT                         |
|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------|-------|------------------------------|
| Input offset voltage                | $T_J = 25^\circ\text{C}$                                                                                                                               |     | 0.3   | 2     | mV                           |
|                                     | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                                                    |     |       | 3     | mV                           |
| Input offset current <sup>(2)</sup> | $T_J = 25^\circ\text{C}$                                                                                                                               |     | 0.25  | 0.7   | nA                           |
|                                     | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                                                    |     |       | 1.5   | nA                           |
| Input bias current                  | $T_J = 25^\circ\text{C}$                                                                                                                               |     | 10    | 20    | nA                           |
|                                     | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                                                    |     |       | 30    | nA                           |
| Input resistance                    | $T_J = 25^\circ\text{C}$                                                                                                                               | 250 | 500   |       | k $\Omega$                   |
|                                     | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                                                    | 150 |       |       | k $\Omega$                   |
| Large signal voltage gain           | $V_S = \pm 20\text{ V}$ , $I_{\text{OUT}} = 0$                                                                                                         | 120 | 400   |       | V/mV                         |
|                                     | $V_{\text{OUT}} = \pm 19.95\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                            | 80  |       |       | V/mV                         |
|                                     | $V_S = \pm 20\text{ V}$ , $V_{\text{OUT}} = \pm 19.4\text{ V}$                                                                                         | 50  | 130   |       | V/mV                         |
|                                     | $I_{\text{OUT}} = \pm 20\text{ mA}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                              | 20  |       |       | V/mV                         |
|                                     | $I_{\text{OUT}} = \pm 15\text{ mA}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                              | 20  |       |       | V/mV                         |
|                                     | $V_S = \pm 0.6\text{ V}$ , $I_{\text{OUT}} = \pm 2\text{ mA}$                                                                                          | 1.5 | 3     |       | V/mV                         |
|                                     | $V_S = \pm 0.65\text{ V}$ , $I_{\text{OUT}} = \pm 2\text{ mA}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                   | 1.5 | 3     |       | V/mV                         |
|                                     | $V_{\text{OUT}} = \pm 0.4\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                              | 0.5 |       |       | V/mV                         |
|                                     | $V_{\text{OUT}} = \pm 0.3\text{ V}$ , $V_{\text{CM}} = -0.4\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )            | 0.5 |       |       | V/mV                         |
| Shunt gain <sup>(3)</sup>           | $1.2\text{ V} \leq V_{\text{OUT}} \leq 40\text{ V}$ , $R_L = 1.1\text{ k}\Omega$                                                                       | 14  | 33    |       | V/mV                         |
|                                     | $1.3\text{ V} \leq V_{\text{OUT}} \leq 40\text{ V}$ , $R_L = 1.1\text{ k}\Omega$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> ) | 14  | 33    |       | V/mV                         |
|                                     | $0.1\text{ mA} \leq I_{\text{OUT}} \leq 5\text{ mA}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                             | 6   |       |       | V/mV                         |
|                                     | $1.5\text{ V} \leq V^+ \leq 40\text{ V}$ , $R_L = 250\text{ }\Omega$                                                                                   | 8   | 25    |       | V/mV                         |
|                                     | $0.1\text{ mA} \leq I_{\text{OUT}} \leq 20\text{ mA}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                            | 4   |       |       | V/mV                         |
| Common-mode rejection               | $-20\text{ V} \leq V_{\text{CM}} \leq 19.15\text{ V}$                                                                                                  | 93  | 102   |       | dB                           |
|                                     | $-20\text{ V} \leq V_{\text{CM}} \leq 19\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                               | 93  | 102   |       | dB                           |
|                                     | $V_S = \pm 20\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                          | 87  |       |       | dB                           |
| Supply-voltage rejection            | $-0.2\text{ V} \geq V^- \geq -39\text{ V}$                                                                                                             | 90  | 96    |       | dB                           |
|                                     | $V^+ = 1\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                               | 84  |       |       | dB                           |
|                                     | $V^+ = 1.1\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                             | 84  |       |       | dB                           |
|                                     | $1\text{ V} \leq V^+ \leq 39.8\text{ V}$                                                                                                               | 96  | 106   |       | dB                           |
|                                     | $1.1\text{ V} \leq V^+ \leq 39.8\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                       | 96  | 106   |       | dB                           |
|                                     | $V^- = -0.2\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                                            | 90  |       |       | dB                           |
| Offset voltage drift                |                                                                                                                                                        |     | 2     |       | $\mu\text{V}/^\circ\text{C}$ |
| Offset current drift                |                                                                                                                                                        |     | 2     |       | pA/ $^\circ\text{C}$         |
| Bias current drift                  | $T_C < 100^\circ\text{C}$                                                                                                                              |     | 60    |       | pA/ $^\circ\text{C}$         |
| Line regulation                     | $1.2\text{ V} \leq V_S \leq 40\text{ V}$                                                                                                               |     | 0.001 | 0.003 | %/V                          |
|                                     | $1.3\text{ V} \leq V_S \leq 40\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                         |     | 0.001 | 0.003 | %/V                          |
|                                     | $0 \leq I_{\text{REF}} \leq 1\text{ mA}$ , $V_{\text{REF}} = 200\text{ mV}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )      |     |       | 0.006 | %/V                          |
| Load regulation                     | $0 \leq I_{\text{REF}} \leq 1\text{ mA}$                                                                                                               |     | 0.01% | 0.1%  |                              |
|                                     | $V^+ - V_{\text{REF}} \geq 1\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                           |     |       | 0.15% |                              |
|                                     | $V^+ - V_{\text{REF}} \geq 1.1\text{ V}$ , $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> )                                         |     |       | 0.15% |                              |

(1) These specifications apply for  $V^- \leq V_{\text{CM}} \leq V^+ - 0.85\text{ V}$ ,  $1\text{ V}$  ( $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ ),  $1.2\text{ V}$ ,  $1.3\text{ V}$  ( $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ )  $< V_S \leq V_{\text{MAX}}$ ,  $V_{\text{REF}} = 0.2\text{ V}$  and  $0 \leq I_{\text{REF}} \leq 1\text{ mA}$ , unless otherwise specified:  $V_{\text{MAX}} = 40\text{ V}$  for the standard part and  $6.5\text{ V}$  for the low voltage part. The full-temperature-range operation is  $-55^\circ\text{C}$  to  $125^\circ\text{C}$  for the LM10-MIL. The specifications do not include the effects of thermal gradients ( $\tau_1 \approx 20\text{ ms}$ ), die heating ( $\tau_2 \approx 0.2\text{ s}$ ) or package heating. Gradient effects are small and tend to offset the electrical error (see curves).

(2) For  $T_J > 90^\circ\text{C}$ ,  $I_{\text{OS}}$  may exceed  $1.5\text{ nA}$  for  $V_{\text{CM}} = V^-$ . With  $T_J = 125^\circ\text{C}$  and  $V^- \leq V_{\text{CM}} \leq V^+ + 0.1\text{ V}$ ,  $I_{\text{OS}} \leq 5\text{ nA}$ .

(3) This defines operation in floating applications such as the bootstrapped regulator or two-wire transmitter. Output is connected to the  $V^+$  terminal of the IC and input common mode is referred to  $V^-$  (see [System Examples](#)). Effect of larger output-voltage swings with higher load resistance can be accounted for by adding the positive-supply rejection error.

## Electrical Characteristics (continued)

 $T_J = 25^\circ\text{C}$  unless otherwise specified<sup>(1)</sup>

| PARAMETER              | TEST CONDITIONS                                                     |                                                                     | MIN | TYP   | MAX | UNIT                |
|------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|-----|-------|-----|---------------------|
| Amplifier gain         | $0.2\text{ V} \leq V_{\text{REF}} \leq 35\text{ V}$                 | $T_J = 25^\circ\text{C}$                                            | 50  | 75    |     | V/mV                |
|                        |                                                                     | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> ) | 23  |       |     | V/mV                |
| Feedback sense voltage | $T_J = 25^\circ\text{C}$                                            |                                                                     | 195 | 200   | 205 | mV                  |
|                        | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> ) |                                                                     | 194 |       | 206 | mV                  |
| Feedback current       | $T_J = 25^\circ\text{C}$                                            |                                                                     |     | 20    | 50  | nA                  |
|                        | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> ) |                                                                     |     |       | 65  | nA                  |
| Reference drift        |                                                                     |                                                                     |     | 0.002 |     | %/ $^\circ\text{C}$ |
| Supply current         | $T_J = 25^\circ\text{C}$                                            |                                                                     |     | 270   | 400 | $\mu\text{A}$       |
|                        | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> ) |                                                                     |     |       | 500 | $\mu\text{A}$       |
| Supply current change  | $1.2\text{ V} \leq V_S \leq 40\text{ V}$                            | $T_J = 25^\circ\text{C}$                                            |     | 15    |     | $\mu\text{A}$       |
|                        |                                                                     | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> ) |     |       | 75  |                     |
|                        | $1.3\text{ V} \leq V_S \leq 40\text{ V}$                            | $T_J = 25^\circ\text{C}$                                            |     | 15    |     | $\mu\text{A}$       |
|                        |                                                                     | $T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$ (see <sup>(1)</sup> ) |     |       | 75  |                     |

## 6.5 Typical Characteristics

### 6.5.1 Typical Characteristics (Op Amp)

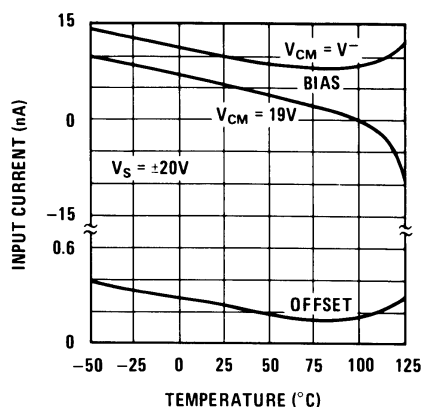


Figure 1. Input Current

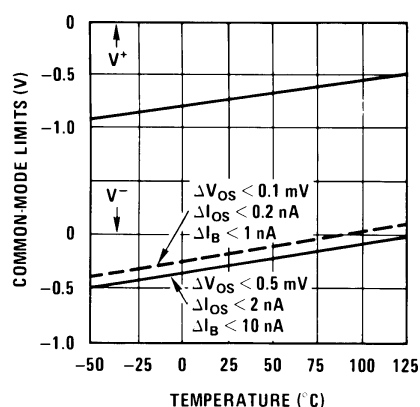


Figure 2. Common-Mode Limits

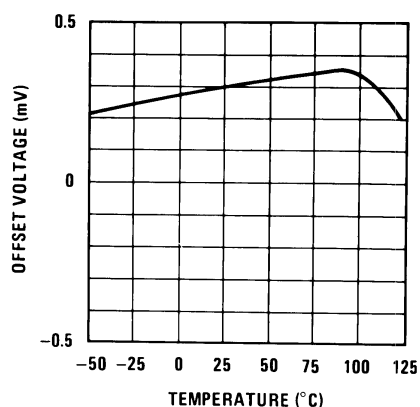


Figure 3. Output Voltage Drift

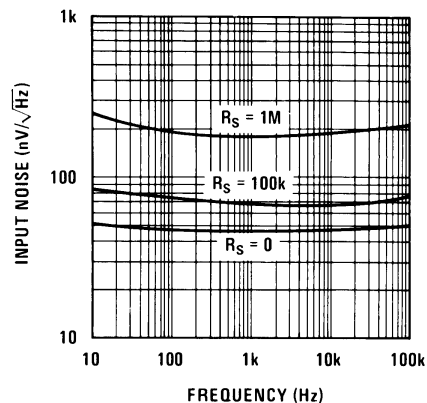


Figure 4. Input Noise Voltage

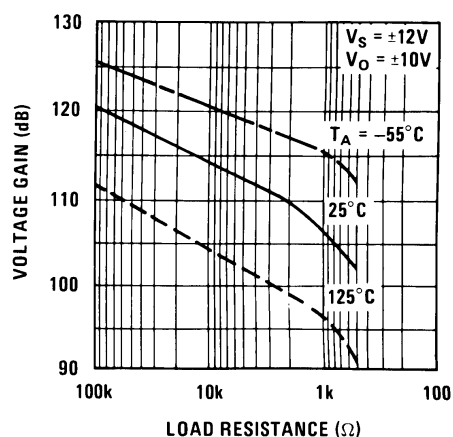


Figure 5. DC Voltage Gain

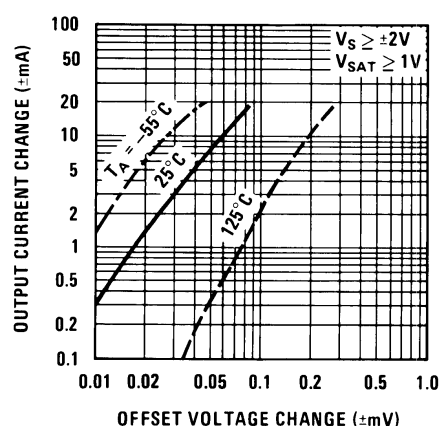


Figure 6. Transconductance

## Typical Characteristics (Op Amp) (continued)

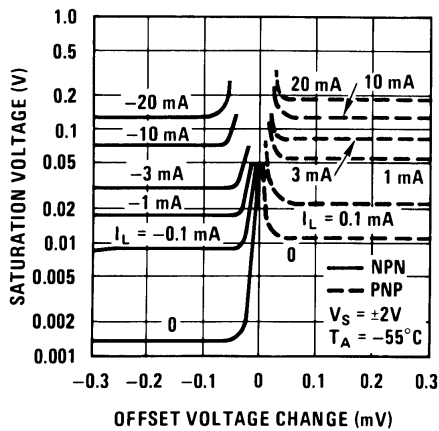


Figure 7. Output Saturation Characteristics

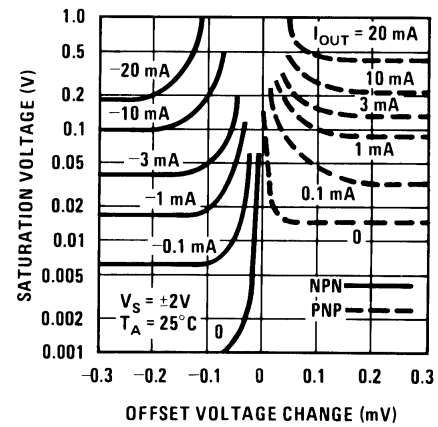


Figure 8. Output Saturation Characteristics

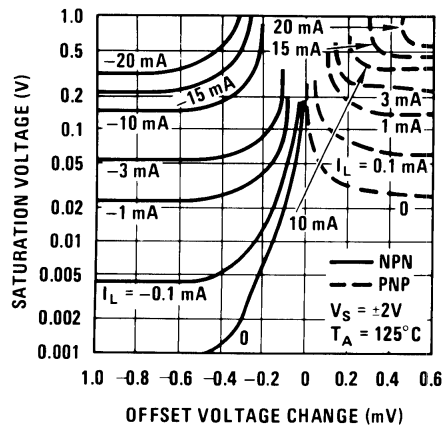


Figure 9. Output Saturation Characteristics

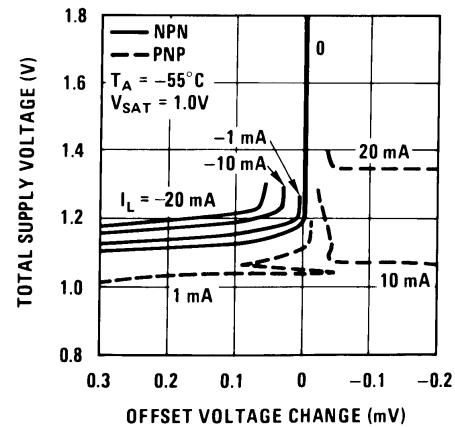


Figure 10. Minimum Supply Voltage

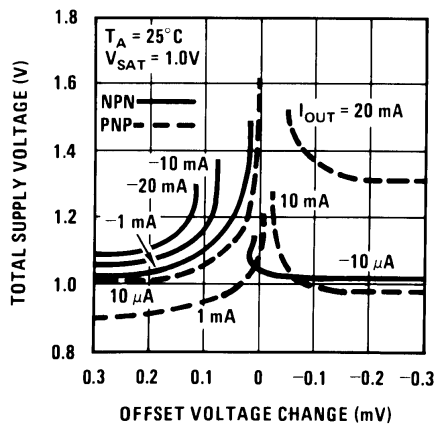


Figure 11. Minimum Supply Voltage

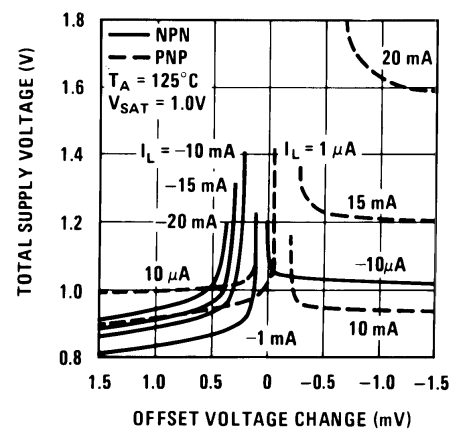


Figure 12. Minimum Supply Voltage

## Typical Characteristics (Op Amp) (continued)

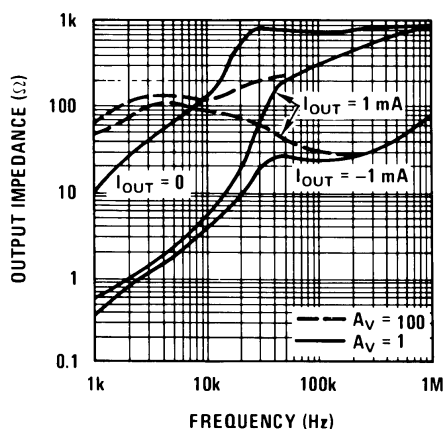


Figure 13. Output Impedance

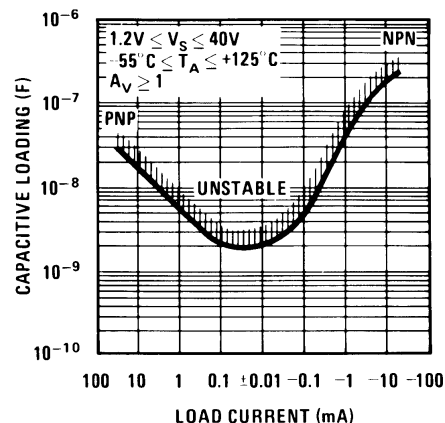


Figure 14. Typical Stability Range

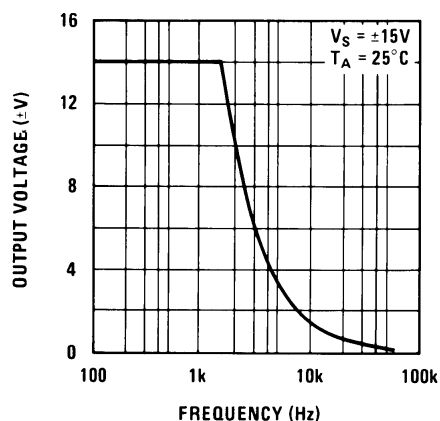


Figure 15. Large Signal Response

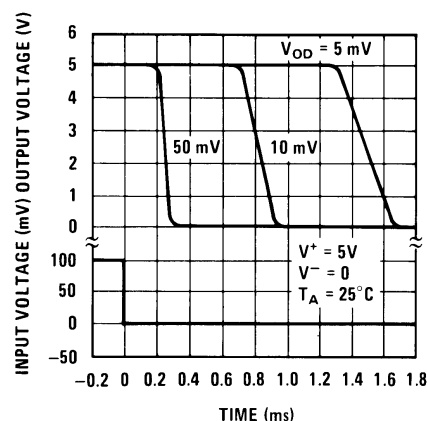


Figure 16. Comparator Response Time For Various Input Overdrives

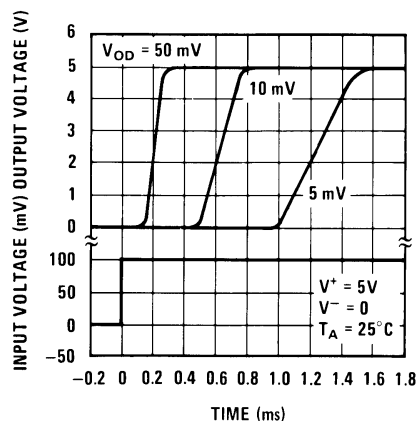


Figure 17. Comparator Response Time For Various Input Overdrives

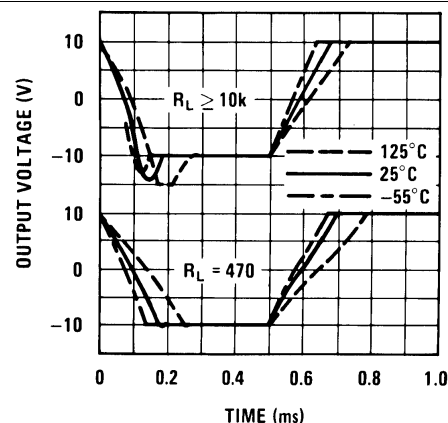


Figure 18. Follower Pulse Response

## Typical Characteristics (Op Amp) (continued)

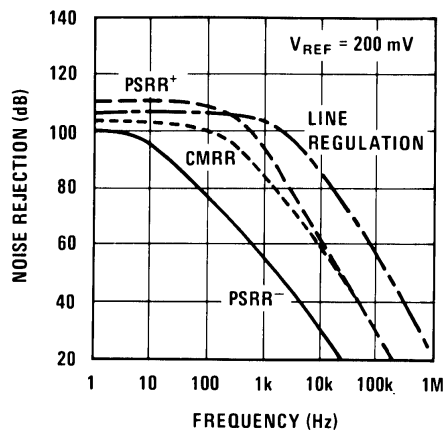


Figure 19. Noise Rejection

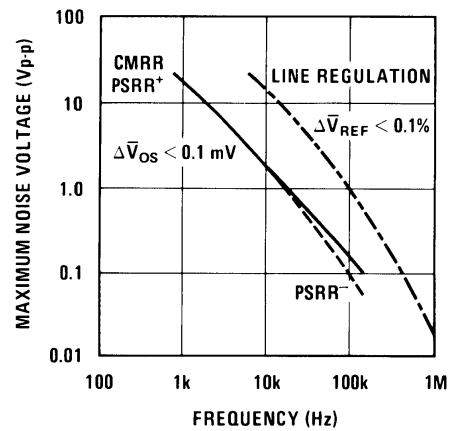


Figure 20. Rejection Slew Limiting

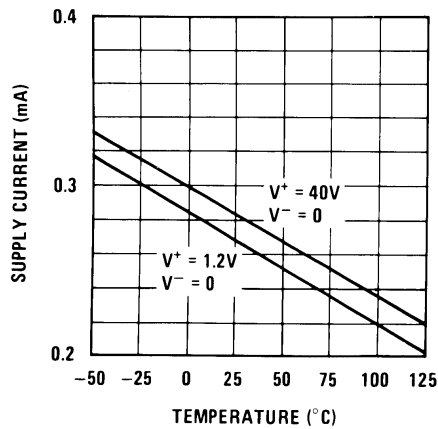


Figure 21. Supply Current

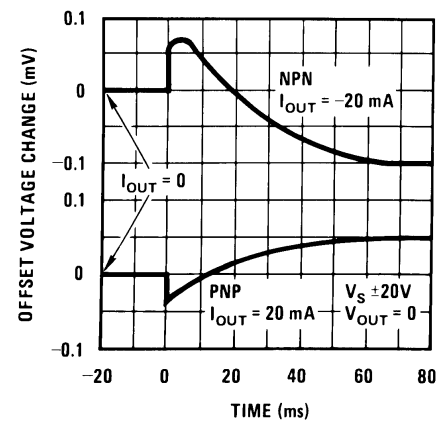


Figure 22. Thermal Gradient Feedback

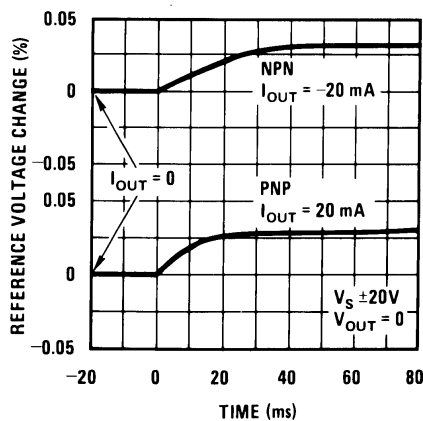


Figure 23. Thermal Gradient Cross-Coupling

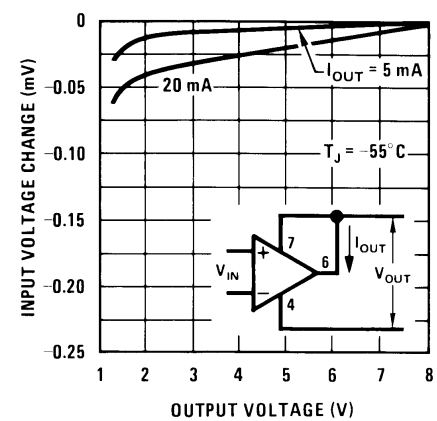


Figure 24. Shunt Gain

## Typical Characteristics (Op Amp) (continued)

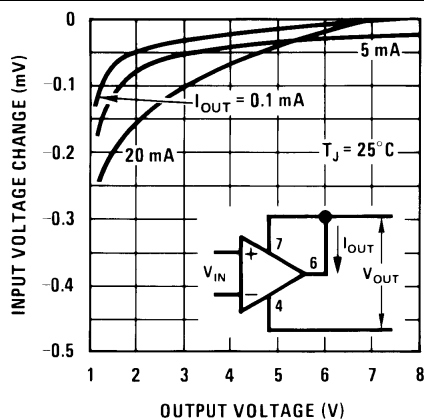


Figure 25. Shunt Gain

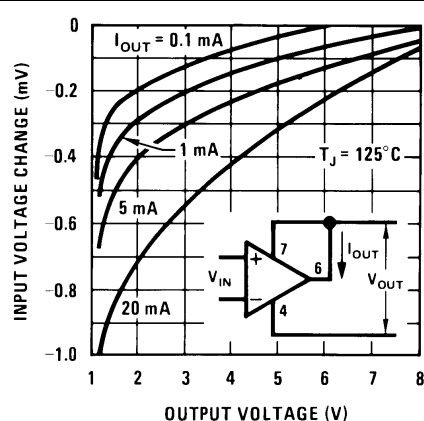


Figure 26. Shunt Gain

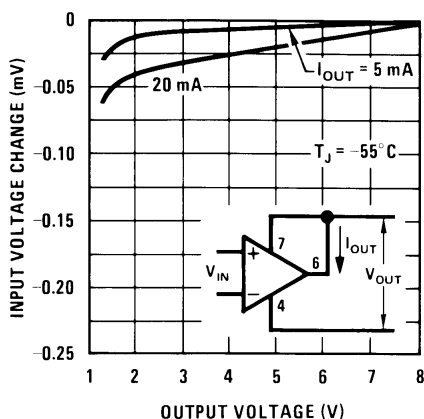


Figure 27. Shunt Gain

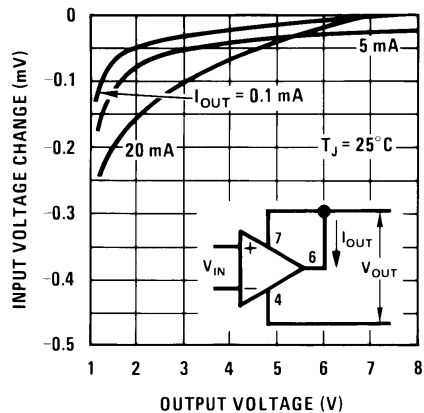


Figure 28. Shunt Gain

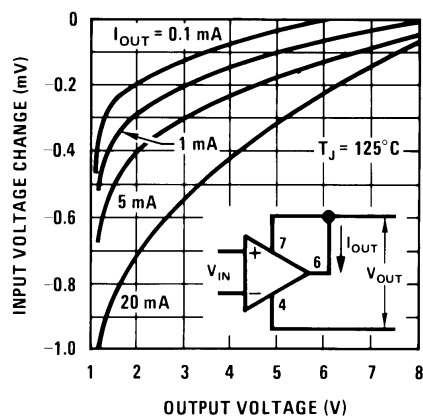


Figure 29. Shunt Gain

## 6.5.2 Typical Characteristics (Reference)

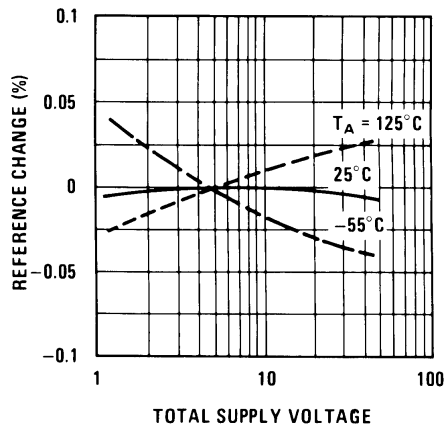


Figure 30. Line Regulation

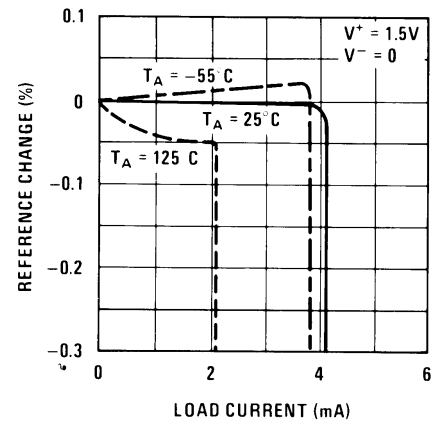


Figure 31. Load Regulation

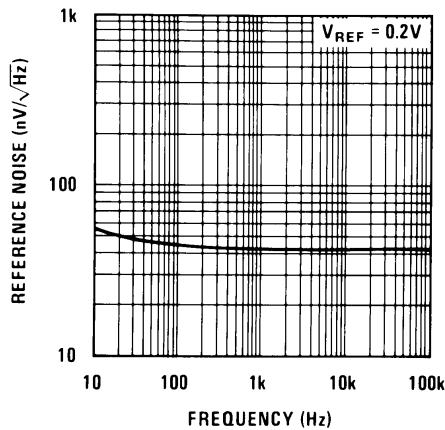


Figure 32. Reference Noise Voltage

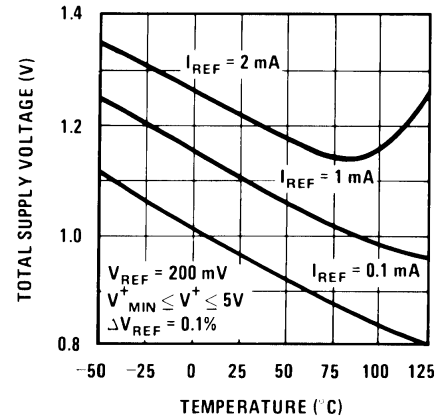


Figure 33. Minimum Supply Voltage

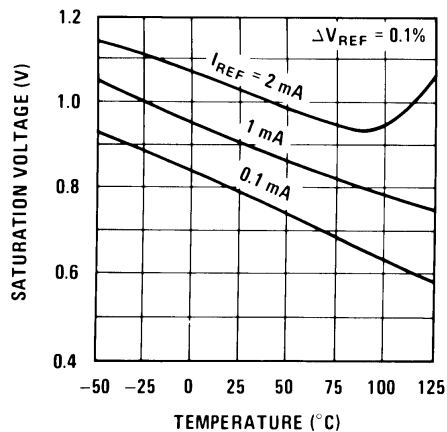


Figure 34. Output Saturation

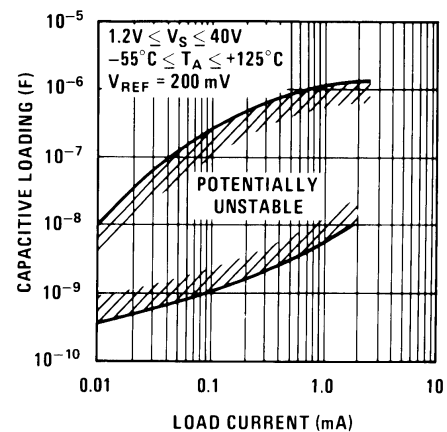


Figure 35. Typical Stability Range



## 8 Application and Implementation

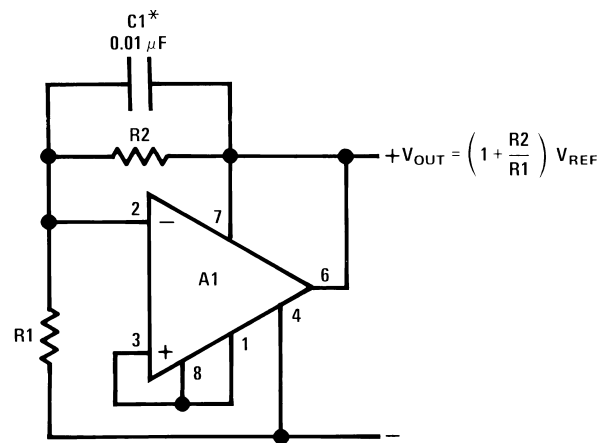
### NOTE

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

With heavy amplifier loading to  $V^-$ , resistance drops in the  $V^-$  lead can adversely affect reference regulation. Lead resistance can approach  $1\ \Omega$ . Therefore, the common to the reference circuitry should be connected as close as possible to the package.

### 8.2 Typical Application



\* required for capacitive loading

**Figure 36. Shunt Voltage Regulator**

#### 8.2.1 Design Requirements

Table 1 lists the design parameters for this example.

**Table 1. Design Parameters**

| DESIGN PARAMETERS         | EXAMPLE VALUE         |
|---------------------------|-----------------------|
| Ambient Temperature Range | –55°C to 125°C        |
| Supply Voltage Range      | 1.2 V to 40 V         |
| Common-Mode Input Range   | (V–) to (V+) – 0.85 V |

#### 8.2.2 Detailed Design Procedure

Given that the transfer function of this circuit is:

$$V_{OUT} = \left(1 + \frac{R_2}{R_1}\right) V_{REF} \quad (1)$$

the output can be set between 0.2 V and the breakdown voltage of the IC by selecting an appropriate value for R2. The circuit regulates for input voltages within a saturation drop of the output (typically 0.4 V at 20 mA and 0.15 V at 5 mA). The regulator is protected from shorts or overloads by current limiting and thermal shutdown.

Typical regulation is about 0.05% load and 0.003%/V line. A substantial improvement in regulation can be effected by connecting the operational amplifier as a follower and setting the reference to the desired output voltage. This has the disadvantage that the minimum input-output differential is increased to a little more than a diode drop. If the operational amplifier were connected for a gain of 2, the output could again saturate. But this requires an additional pair of precision resistors.

The regulator in [Figure 36](#) could be made adjustable to zero by connecting the operational amplifier to a potentiometer on the reference output. This has the disadvantage that the regulation at the lower voltage settings is not as good as it might otherwise be.

### 8.2.3 Application Curve

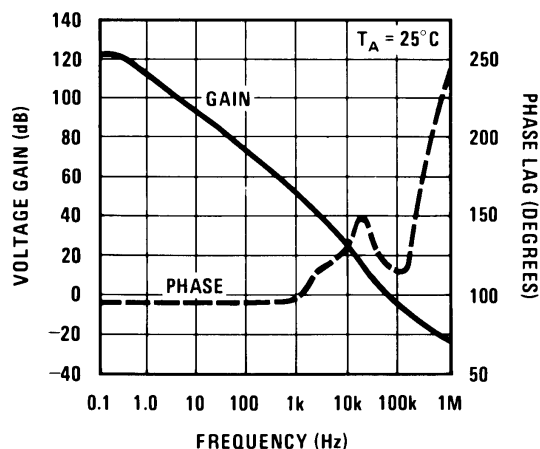


Figure 37. Frequency Response

## 8.3 System Examples

Circuit descriptions available in application note AN-211 ([SNOA638](#)).

### 8.3.1 Operational Amplifier Offset Adjustment

(Pin numbers are for 8-pin packages)

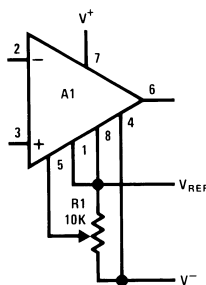


Figure 38. Standard

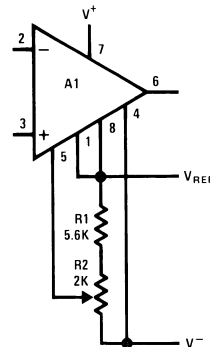
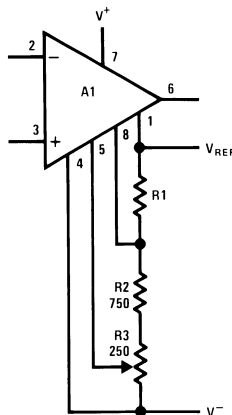


Figure 39. Limited Range

## System Examples (continued)

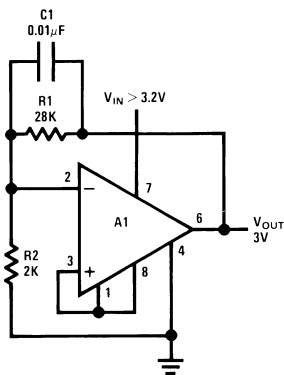
(Pin numbers are for 8-pin packages)



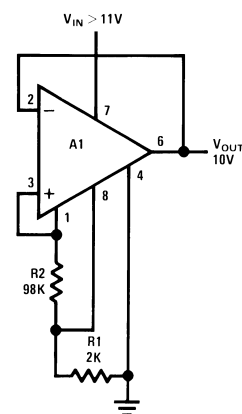
**Figure 40. Limited Range With Boosted Reference**

### 8.3.2 Positive Regulators

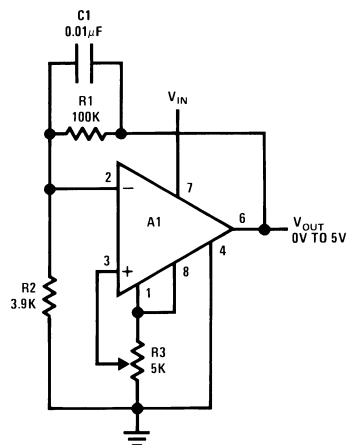
(Pin numbers are for 8-pin packages)



**Figure 41. Low Voltage**

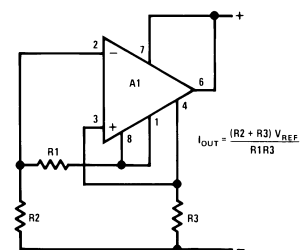


**Figure 42. Best Regulation**



Use only electrolytic output capacitors.

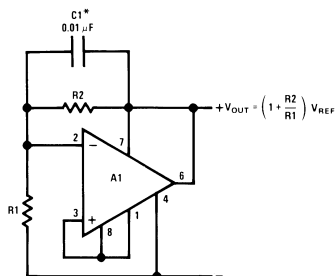
**Figure 43. Zero Output**



**Figure 44. Current Regulator**

## System Examples (continued)

(Pin numbers are for 8-pin packages)



Required For Capacitive Loading

Figure 45. Shunt Regulator

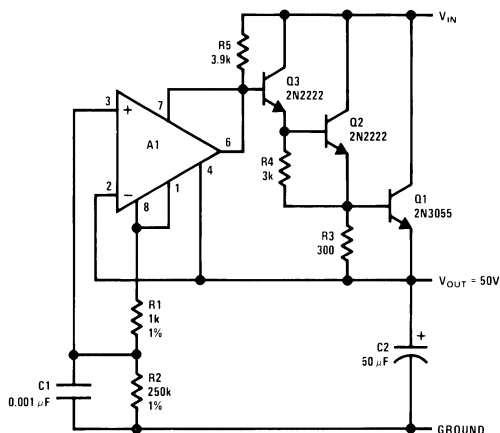
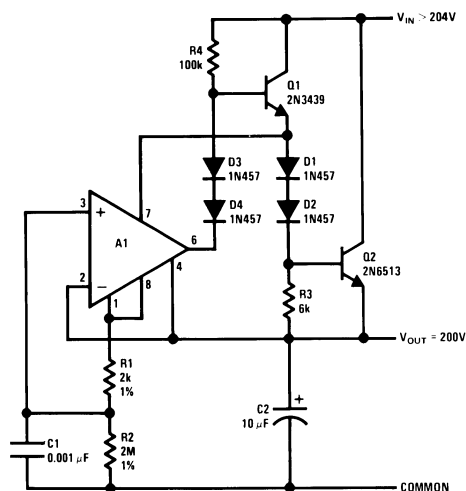
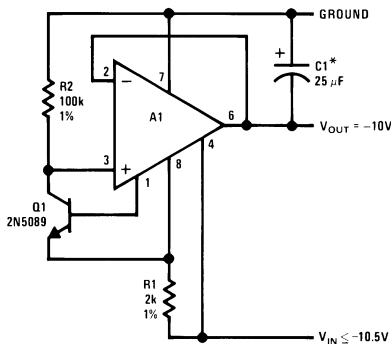


Figure 47. Precision Regulator



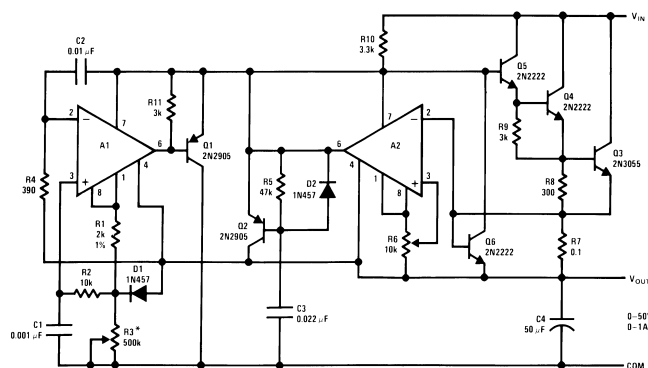
$$V_{OUT} = \frac{R2}{R1} V_{REF}$$

Figure 49. HV Regulator



\*Electrolytic

Figure 46. Negative Regulator



$$*V_{OUT} = 10^{-4} R3$$

Figure 48. Laboratory Power Supply

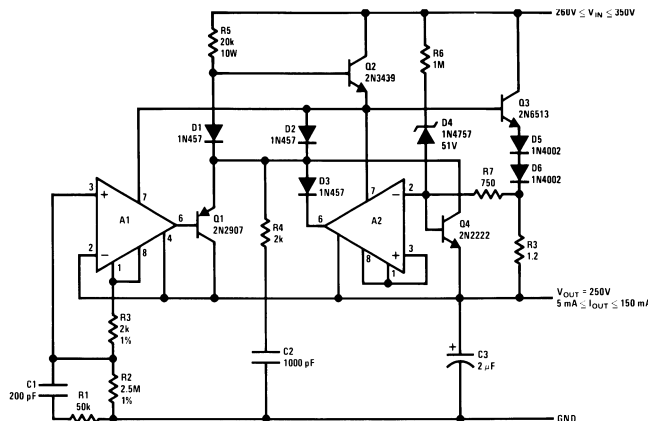
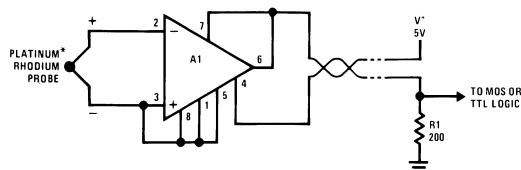


Figure 50. Protected HV Regulator

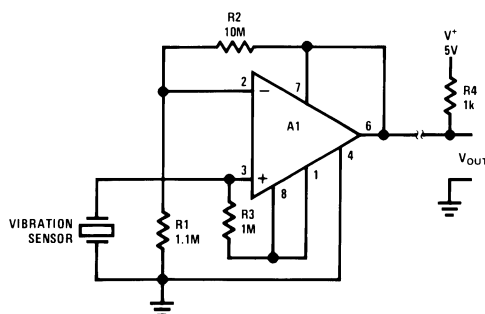
## System Examples (continued)

(Pin numbers are for 8-pin packages)

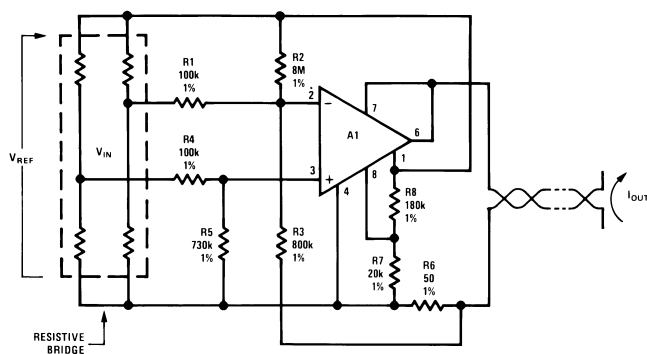


\*800°C Threshold Is Established By Connecting Balance To  $V_{REF}$ .

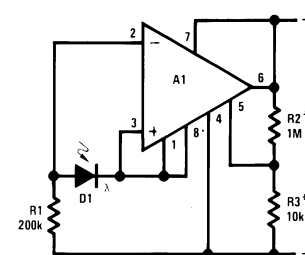
**Figure 51. Flame Detector**



**Figure 53. Remote Amplifier**

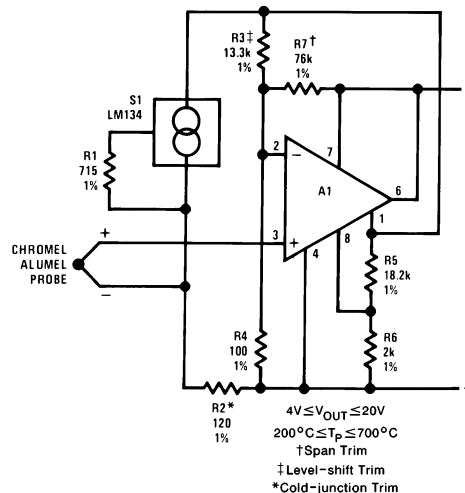


**Figure 55. Transmitter for Bridge Sensor**

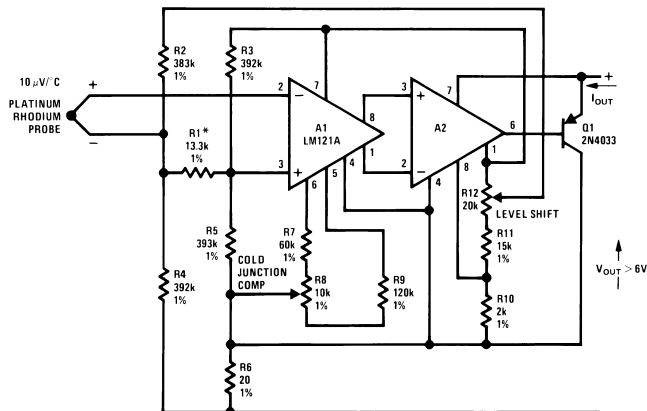


\*Provides Hysteresis

**Figure 52. Light Level Sensor**



**Figure 54. Remote Thermocouple Amplifier**

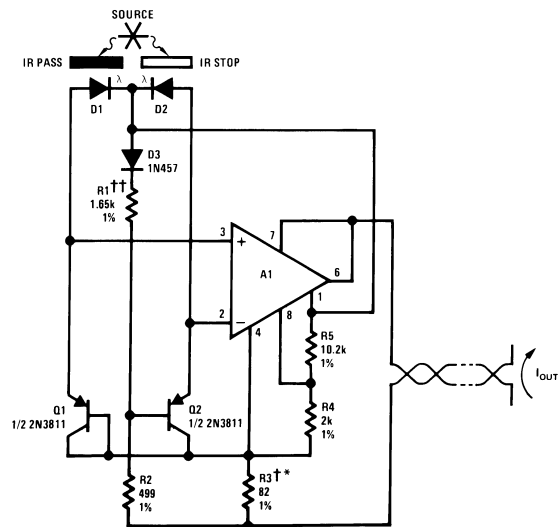
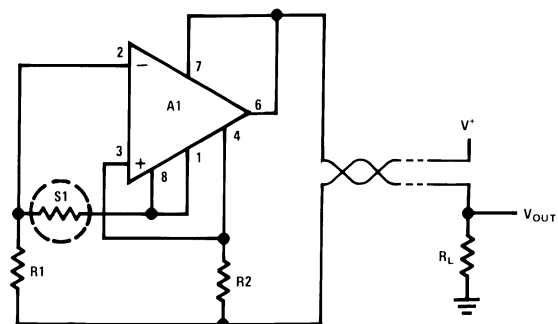


10 mA ≤  $I_{OUT}$  ≤ 50 mA  
500°C ≤  $T_P$  ≤ 1500°C  
\*Gain Trim

**Figure 56. Precision Thermocouple Transmitter**

## System Examples (continued)

(Pin numbers are for 8-pin packages)



††Level-shift Trim

\*Scale Factor Trim

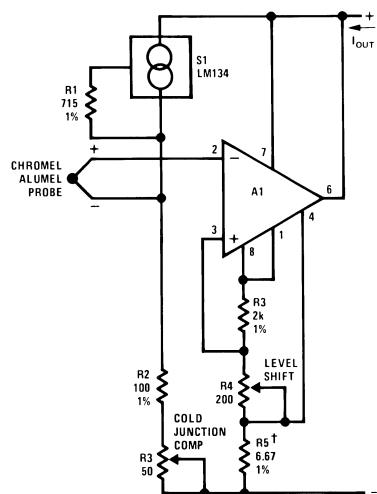
†Copper Wire Wound

$1 \text{ mA} \leq I_{OUT} \leq 5 \text{ mA}$

$0.01 \leq \frac{I_{D2}}{I_{D1}} \leq 100$

Figure 57. Resistance Thermometer Transmitter

Figure 58. Optical Pyrometer

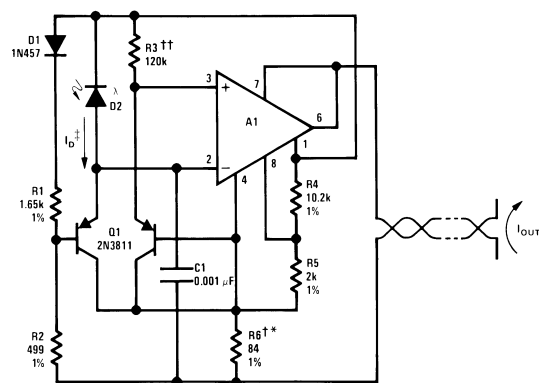


$200^{\circ}\text{C} \leq T_P \leq 700^{\circ}\text{C}$

$1 \text{ mA} \leq I_{OUT} \leq 5 \text{ mA}$

†Gain Trim

Figure 59. Thermocouple Transmitter



$1 \text{ mA} \leq I_{OUT} \leq 5 \text{ mA}$

$\pm 50 \mu\text{A} \leq I_D \leq 500 \mu\text{A}$

††Center Scale Trim

†Scale Factor Trim

\*Copper Wire Wound

Figure 60. Logarithmic Light Sensor

## System Examples (continued)

(Pin numbers are for 8-pin packages)

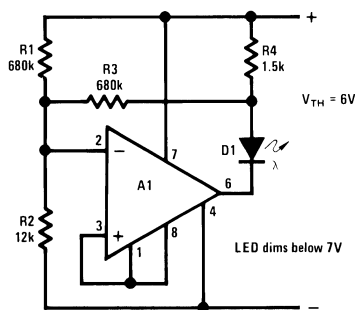


Figure 61. Battery-level Indicator

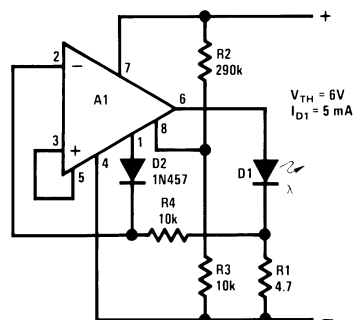
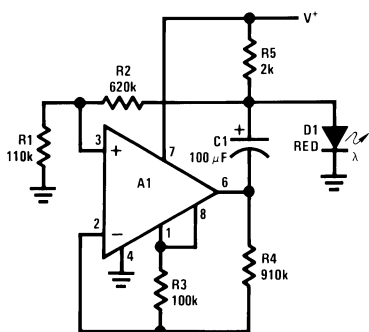
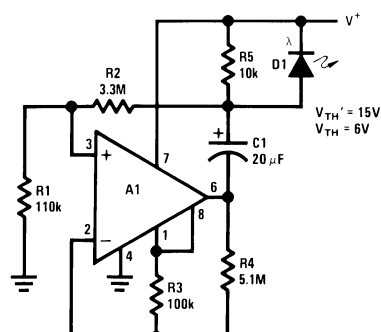


Figure 62. Battery-threshold Indicator



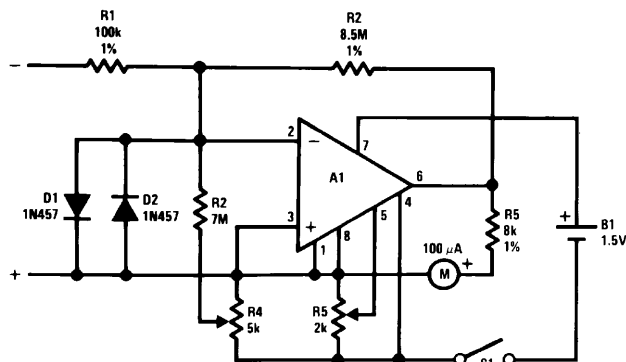
Flashes Above 1.2V  
Rate Increases With  
Voltage

Figure 63. Single-cell Voltage Monitor



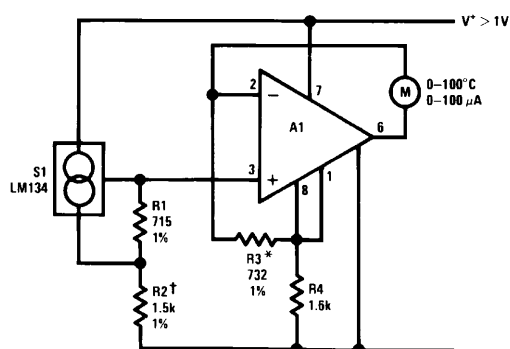
Flash Rate Increases  
Above 6V and Below 15V

Figure 64. Double-ended Voltage Monitor



INPUT  
10 mV, 100nA  
FULL-SCALE

Figure 65. Meter Amplifier



\*Trim For Span  
†Trim For Zero

Figure 66. Thermometer

## System Examples (continued)

(Pin numbers are for 8-pin packages)

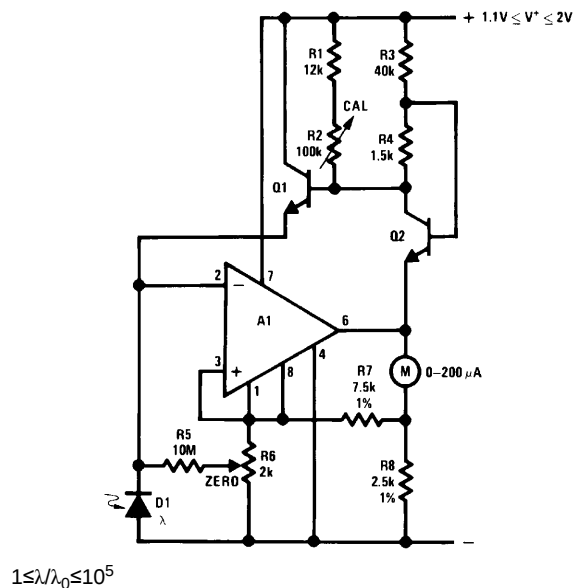


Figure 67. Light Meter

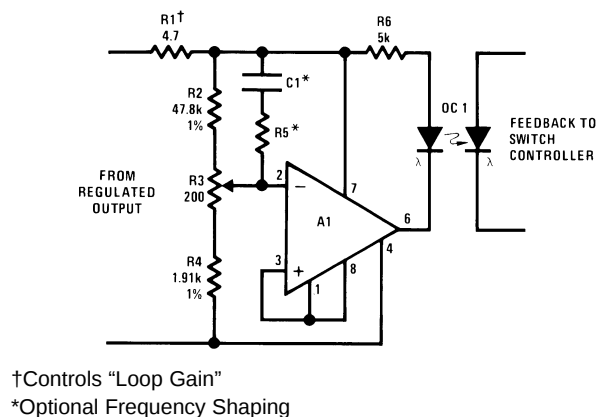
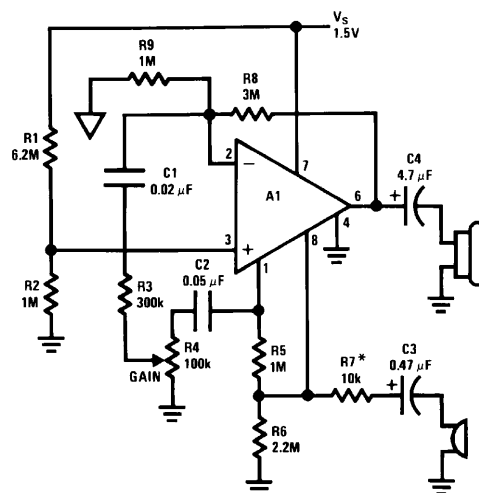


Figure 69. Isolated Voltage Sensor



$Z_{OUT} \sim 680\Omega @ 5 \text{ kHz}$   
 $A_V \leq 1k$   
 $f_1 \sim 100 \text{ Hz}$   
 $f_2 \sim 5 \text{ kHz}$   
 $R_L \sim 500$   
 \*Max Gain Trim

Figure 68. Microphone Amplifier

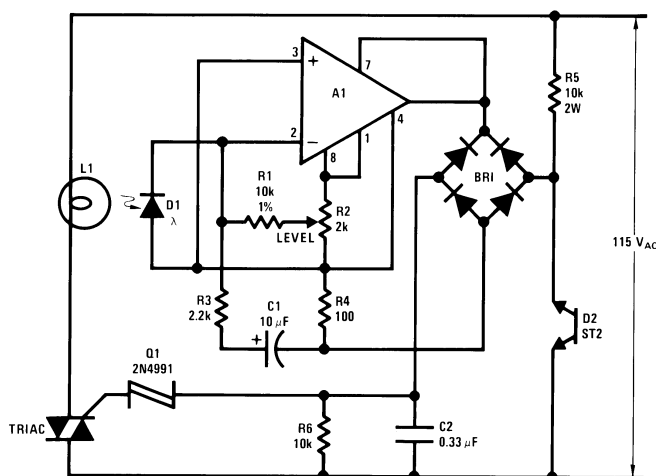
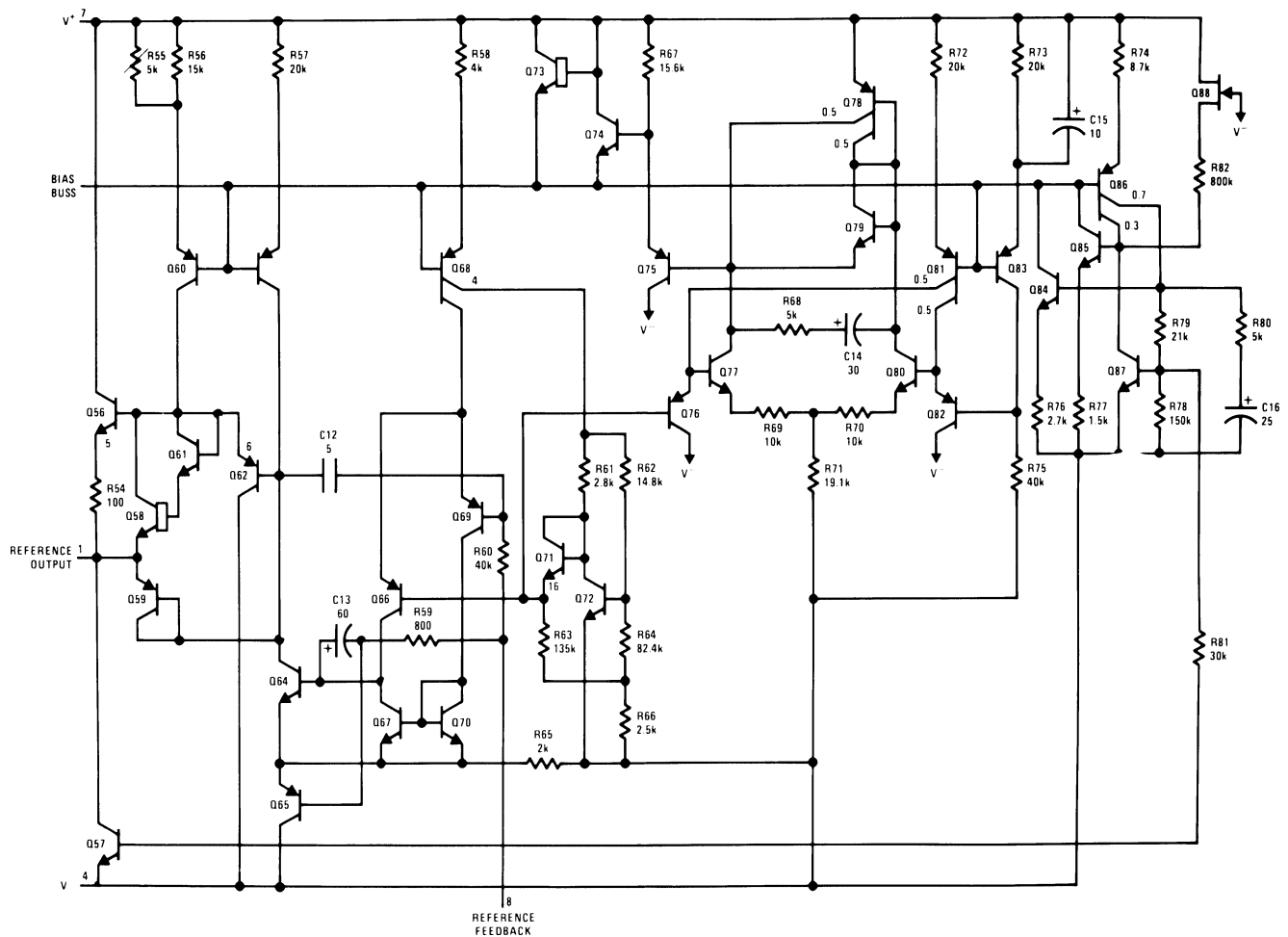


Figure 70. Light-Level Controller

## System Examples (continued)

(Pin numbers are for 8-pin packages)

### 8.3.3 Reference and Internal Regulator



**Figure 71. Reference and Internal Regulator**

## 9 Power Supply Recommendations

The LM10-MIL is specified for operation from 1.2 V to 40 V unless otherwise stated. Many specifications apply from –55°C to 125°C. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in the [Specifications](#) section.

### CAUTION

Supply voltages larger than 40 V can permanently damage the device; see the [Absolute Maximum Ratings](#) table.

## 10 Layout

### 10.1 Layout Guidelines

For best operational performance of the device, good printed-circuit board (PCB) layout practices are recommended. Low-loss, 0.1- $\mu$ F bypass capacitors should be connected between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable to single-supply applications.

### 10.2 Layout Example

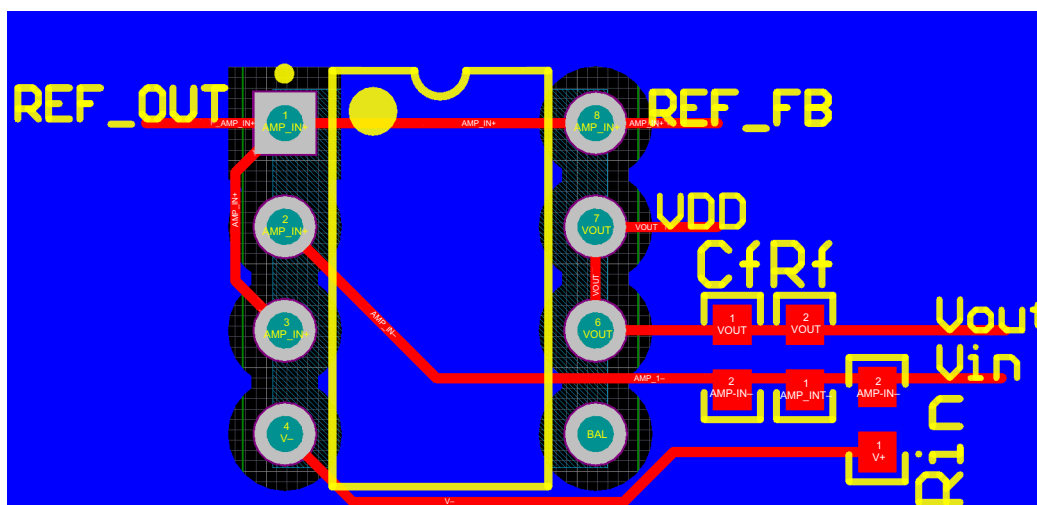


Figure 72. Layout Example

## 11 Device and Documentation Support

### 11.1 Device Support

#### 11.1.1 Device Nomenclature

##### 11.1.1.1 Definition of Terms

**Input offset voltage:** That voltage which must be applied between the input terminals to bias the unloaded output in the linear region.

**Input offset current:** The difference in the currents at the input terminals when the unloaded output is in the linear region.

**Input bias current:** The absolute value of the average of the two input currents.

**Input resistance:** The ratio of the change in input voltage to the change in input current on either input with the other grounded.

**Large signal voltage gain:** The ratio of the specified output voltage swing to the change in differential input voltage required to produce it.

**Shunt gain:** The ratio of the specified output voltage swing to the change in differential input voltage required to produce it with the output tied to the  $V^+$  terminal of the IC. The load and power source are connected between the  $V^+$  and  $V^-$  terminals, and input common-mode is referred to the  $V^-$  terminal.

**Common-mode rejection:** The ratio of the input voltage range to the change in offset voltage between the extremes.

**Supply-voltage rejection:** The ratio of the specified supply-voltage change to the change in offset voltage between the extremes.

**Line regulation:** The average change in reference output voltage over the specified supply voltage range.

**Load regulation:** The change in reference output voltage from no load to that load specified.

**Feedback sense voltage:** The voltage, referred to  $V^-$ , on the reference feedback terminal while operating in regulation.

**Reference amplifier gain:** The ratio of the specified reference output change to the change in feedback sense voltage required to produce it.

**Feedback current:** The absolute value of the current at the feedback terminal when operating in regulation.

**Supply current:** The current required from the power source to operate the amplifier and reference with their outputs unloaded and operating in the linear range.

### 11.2 Documentation Support

#### 11.2.1 Related Documentation

For related documentation, see the following:

*AN-211 New Op Amp Ideas*, [SNOA638](#)

### 11.3 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.

## 11.4 Trademarks

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

## 11.5 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.

## 11.6 Glossary

[SLYZ022](#) — *TI Glossary*.

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

## 12 Mechanical, Packaging, and Orderable Information

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

## PACKAGING INFORMATION

| Orderable part number       | Status<br>(1) | Material type<br>(2) | Package   Pins   | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|-----------------------------|---------------|----------------------|------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">LM10BH</a>      | Active        | Production           | TO-CAN (LMG)   8 | 500   TRAY NON-STD    | No          | Call TI                              | Level-1-NA-UNLIM                  | -40 to 85    | ( LM10BH, LM10BH)   |
| <a href="#">LM10BH/NOPB</a> | Active        | Production           | TO-CAN (LMG)   8 | 500   TRAY NON-STD    | Yes         | Call TI                              | Level-1-NA-UNLIM                  | -40 to 85    | ( LM10BH, LM10BH)   |
| <a href="#">LM10CH</a>      | Active        | Production           | TO-CAN (LMG)   8 | 500   TRAY NON-STD    | No          | Call TI                              | Level-1-NA-UNLIM                  | 0 to 70      | ( LM10CH, LM10CH)   |
| <a href="#">LM10CH/NOPB</a> | Active        | Production           | TO-CAN (LMG)   8 | 500   OTHER           | Yes         | Call TI                              | Level-1-NA-UNLIM                  | 0 to 70      | ( LM10CH, LM10CH)   |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts 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.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "-" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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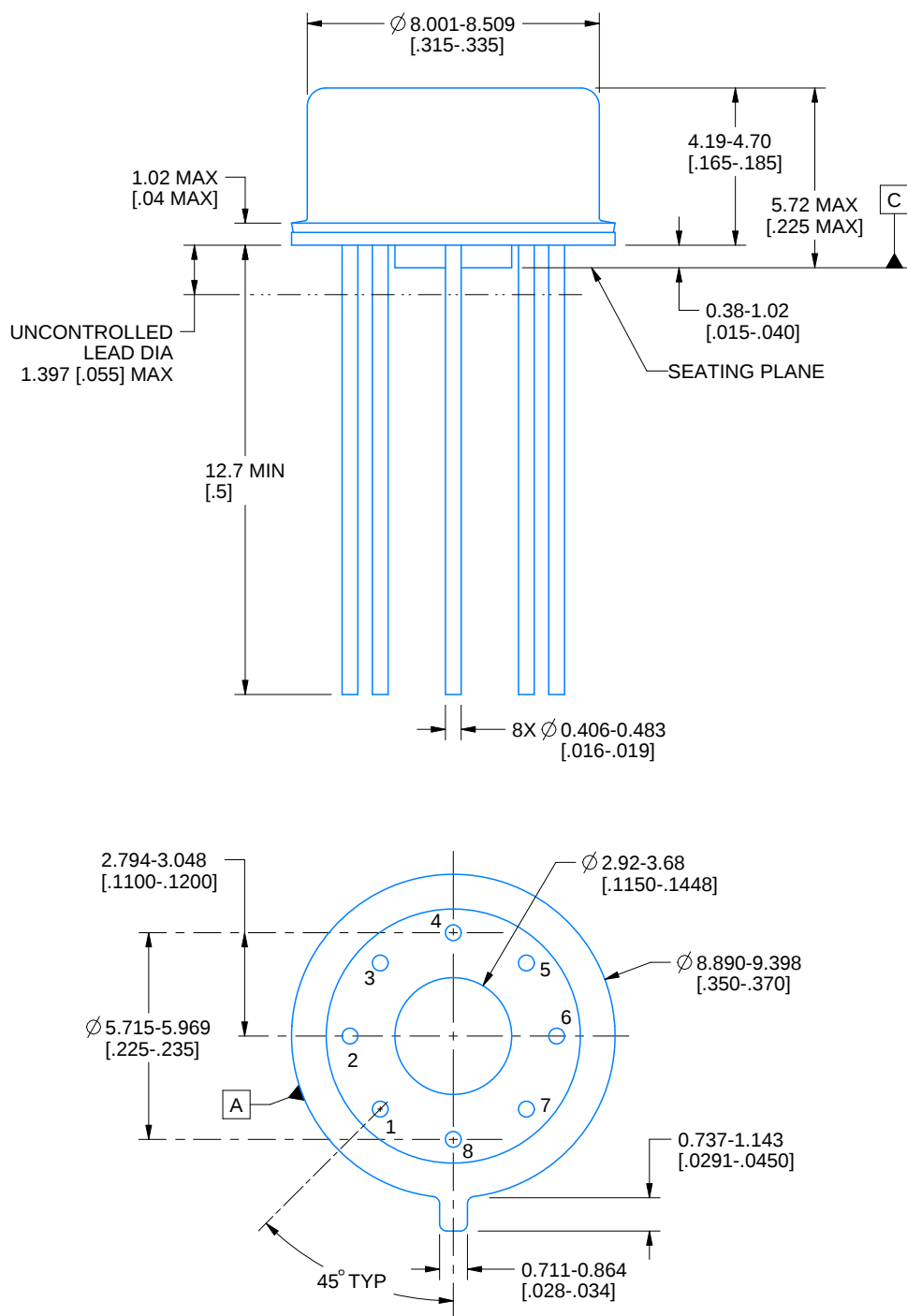
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

# PACKAGE OUTLINE

LMG0008A

TO-CAN - 5.72 mm max height

TRANSISTOR OUTLINE



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## NOTES:

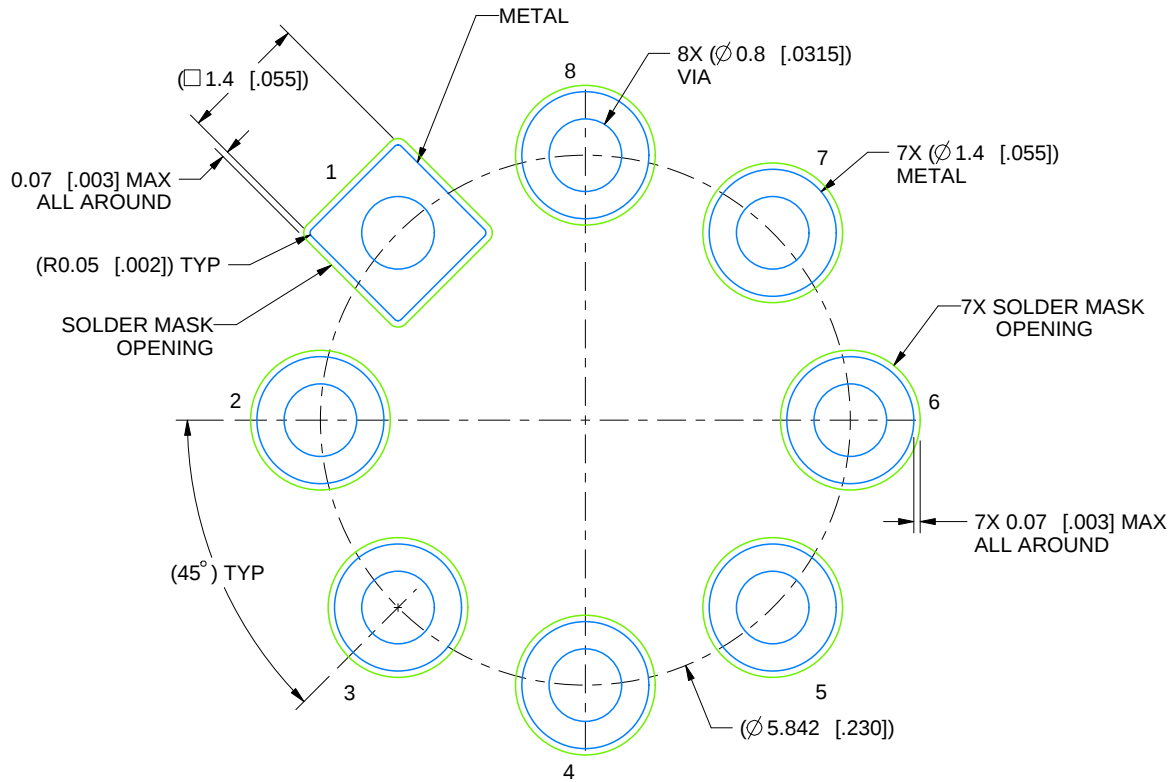
1. All linear dimensions are in millimeters [inches]. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

# EXAMPLE BOARD LAYOUT

LMG0008A

TO-CAN - 5.72 mm max height

TRANSISTOR OUTLINE



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