# Low Power Op Amp and Reference

## FEATURES

- *Guaranteed* Operation at +1.2V
- Op Amp and Reference on Single Chip
- Low Supply Current 400μA
- Capable of Floating Mode Operation
- Low Reference Drift 20ppm/°C
- Low Offset Voltage
- Output Swings to Within 15mV of Rails

## APPLICATIONS

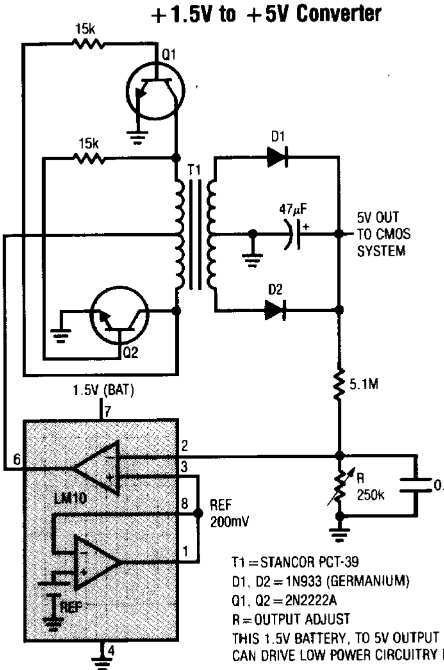
- Remote Signal Conditioner/Transmitter
- Battery Operated Instruments
- Precision Current Regulators
- Precision Voltage Regulators
- Thermocouple Transmitter

## DESCRIPTION

The LM10 combines a precision reference, a reference buffer amplifier and an independent, high quality op amp on a single chip. The device is capable of operation from a single supply as low as 1.1V, from dual supplies up to ±20V and typically draws 270μA supply current. Input voltage range for the op amp includes ground, while the unloaded output can swing to within 15mV of each rail. Further, the LM10 will deliver 20mA output current and still swing within ±400mV of the supply rails.

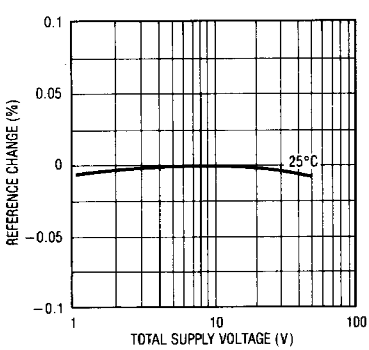
With its low operating current and floating operation capability, the LM10 is ideal for two wire analog transmitter circuits where the processed signal is carried on the same line used for power. The LM10 is suggested for portable battery powered equipment and is fully specified for operation from a single 1.2V battery. Other applications include precision current and voltage regulators, operating from very low voltages to several hundred volts.

**+1.5V to +5V Converter**




T1 = STANCOR PCT-39
D1, D2 = 1N933 (GERMANIUM)
Q1, Q2 = 2N2222A
R = OUTPUT ADJUST
THIS 1.5V BATTERY, TO 5V OUTPUT DESIGN CAN DRIVE LOW POWER CIRCUITRY FOR MONTHS.

**Line Regulation**



## ABSOLUTE MAXIMUM RATINGS

Total Supply Voltage
- LM10/LM10B/LM10C .................. 45V
- LM10BL/LM10CL ........................ 7V

Differential Input Voltage (Note 1)
- LM10/LM10B/LM10C ................ ±40V
- LM10BL/LM10CL ...................... ±7V

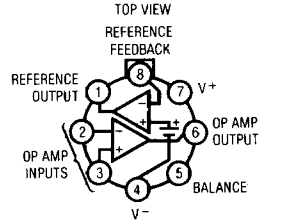
Output Short Circuit Duration .............. Indefinite

Operating Temperature Range (Note 2)
- LM10 .................. $-55°C \le T_A \le 125°C$
- LM10B/LM10BL .......... $-25°C \le T_A \le 85°C$
- LM10C/LM10CL ............. $0°C \le T_A \le 70°C$

Storage Temperature Range .... $-65°C \le T_A \le 150°C$

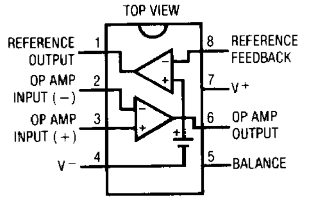
Lead Temperature (Soldering, 10 sec.)......... 300°C

## PACKAGE/ORDER INFORMATION




METAL CAN H PACKAGE

ORDER PART NUMBER: LM10H, LM10BH, LM10CH, LM10BLH, LM10CLH




J8 HERMETIC PACKAGE
N8 PLASTIC DIP PACKAGE

ORDER PART NUMBER: LM10CN8, LM10CLN8, LM10CJ8, LM10CLJ8, LM10J8, LM10BJ8, LM10BLJ8

## OP AMP ELECTRICAL CHARACTERISTICS (Note 3)

| SYMBOL | PARAMETER | CONDITIONS | | LM10/LM10B MIN | TYP | MAX | LM10C MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|
| $V_{OS}$ | Input Offset Voltage | | | | 0.3 | 2.0 | | 0.5 | 4.0 | mV |
| | | | ● | | | 3.0 | | | 5.0 | mV |
| $\frac{\Delta V_{OS}}{\Delta Temp}$ | Average Offset Voltage Drift | | ● | | 2.0 | | | 5.0 | | μV/°C |
| $I_{OS}$ | Input Offset Current | (Note 4) | | | 0.25 | 0.7 | | 0.4 | 2.0 | nA |
| | | | ● | | | 1.5 | | | 3.0 | nA |
| $\frac{\Delta I_{OS}}{\Delta Temp}$ | Offset Current Drift | | ● | | 2.0 | | | 5.0 | | pA/°C |
| $I_B$ | Input Bias Current | | | | 10 | 20 | | 12 | 30 | nA |
| | | | ● | | | 30 | | | 40 | nA |
| $\frac{\Delta I_B}{\Delta Temp}$ | Bias Current Drift | | ● | | 60 | | | 90 | | pA/°C |
| $A_{VOL}$ | Large Signal Voltage Gain | $V_S = \pm 20V$, $I_{OUT} = 0$, $V_{OUT} = \pm 19.95V$ | | 120 | 400 | | 80 | 400 | | V/mV |
| | | | ● | 80 | | | 50 | | | V/mV |
| | | $V_S = \pm 20V$, $V_{OUT} = \pm 19.4V$, $I_{OUT} = \pm 20mA$ | | 50 | 130 | | 25 | 130 | | V/mV |
| | | $I_{OUT} = \pm 15mA$ | ● | 20 | | | 15 | | | V/mV |
| | | $V_S = \pm 0.6V$, $I_{OUT} = \pm 2mA$, $V_{OUT} = \pm 0.4V$, $V_{CM} = -0.4V$ | | 1.5 | 3.0 | | 1.0 | 3.0 | | V/mV |
| | | $V_S = \pm 0.65V$, $I_{OUT} = \pm 2mA$, $V_{OUT} = \pm 0.3V$, $V_{CM} = -0.4V$ | ● | 0.5 | | | 0.75 | | | V/mV |
| | Shunt Gain (Note 5) | $0.1mA \le I_{OUT} \le 5mA$, $R_L = 1.1k\Omega$, $1.2V \le V_{OUT} \le 40V$ | | 14 | 33 | | 10 | 33 | | V/mV |
| | | $1.3V \le V_{OUT} \le 40V$ | ● | 6 | | | 6 | | | V/mV |
| | | $0.1mA \le I_{OUT} \le 20mA$, $R_L = 250\Omega$, $1.5V \le V^+ \le 40V$ | | 8 | 25 | | 6 | 25 | | V/mV |
| | | | ● | 4 | | | 4 | | | V/mV |

# OP AMP ELECTRICAL CHARACTERISTICS (Note 3)

| SYMBOL | PARAMETER | CONDITIONS | | LM10/LM10B MIN | LM10/LM10B TYP | LM10/LM10B MAX | LM10C MIN | LM10C TYP | LM10C MAX | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|
| CMRR | Common-Mode Rejection Ratio | $V_S = \pm 20V$ <br> $-20V \le V_{CM} \le 19.15V$ | | 93 | 102 | | 90 | 102 | | dB |
| | | $-20V \le V_{CM} \le 19V$ | ● | 87 | | | 87 | | | dB |
| PSRR | Power Supply Rejection Ratio | $-0.2V \ge V^- \ge -39V$ <br> $V^+ = 1.0V$ | | 90 | 96 | | 87 | 96 | | dB |
| | | $V^+ = 1.1V$ | ● | 84 | | | 84 | | | dB |
| | | $V^- = -0.2V$ <br> $1.0V \le V^+ \le 39.8V$ | | 96 | 106 | | 93 | 106 | | dB |
| | | $1.1V \le V^+ \le 39.8V$ | ● | 90 | | | 90 | | | dB |
| $R_{IN}$ | Input Resistance | (Note 6) | | 250 | 500 | | 150 | 400 | | kΩ |
| | | | ● | 150 | | | 115 | | | kΩ |
| $I_S$ | Supply Current | | | | 270 | 400 | | 300 | 500 | μA |
| | | | ● | | | 500 | | | 570 | μA |
| $\Delta I_S$ | Supply Current Change | $1.2V \le V_S \le 40V$ | | | 15 | 75 | | 15 | 75 | μA |
| | | $1.3V \le V_S \le 40V$ | ● | | | 75 | | | 75 | μA |

# REFERENCE AMPLIFIER ELECTRICAL CHARACTERISTICS (Note 3)

| SYMBOL | PARAMETER | CONDITIONS | | LM10/LM10B MIN | LM10/LM10B TYP | LM10/LM10B MAX | LM10C MIN | LM10C TYP | LM10C MAX | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|
| $V_{REF}$ | Feedback Sense Voltage | Voltage at Pin 1 with Pin 1 | | 195 | 200 | 205 | 190 | 200 | 210 | mV |
| | | Connected to Pin 8 | ● | 194 | 200 | 206 | 189 | 200 | 211 | mV |
| $\frac{\Delta V_{REF}}{\Delta Temp}$ | Reference Drift | | ● | | 0.002 | | | 0.003 | | %/°C |
| | Feedback Current | Current into Pin 8 | | | 20 | 50 | | 22 | 75 | nA |
| | | | ● | | | 65 | | | 90 | nA |
| | Line Regulation | $0 \le I_{REF} \le 1mA$, $V_{REF} = 200mV$ <br> $1.2V \le V_S \le 40V$ | | | 0.001 | 0.003 | | 0.001 | 0.008 | %/V |
| | | $1.3V \le V_S \le 40V$ | ● | | 0.001 | 0.006 | | 0.001 | 0.01 | %/V |
| | Load Regulation | $0 \le I_{REF} \le 1mA$ <br> $V^+ - V_{REF} \ge 1.0V$ | | | 0.01 | 0.1 | | 0.01 | 0.15 | % |
| | | $V^+ - V_{REF} \ge 1.1V$ | ● | | 0.01 | 0.15 | | 0.01 | 0.20 | % |
| | Reference Amplifier Gain | $0.2V \le V_{REF} \le 35V$ | | 50 | 75 | | 25 | 70 | | V/mV |
| | | | ● | 23 | | | 15 | | | V/mV |

## OP AMP ELECTRICAL CHARACTERISTICS (Note 3)

| SYMBOL | PARAMETER | CONDITIONS | | LM10BL MIN | LM10BL TYP | LM10BL MAX | LM10CL MIN | LM10CL TYP | LM10CL MAX | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|
| $V_{OS}$ | Input Offset Voltage | | | | 0.3 | 2.0 | | 0.5 | 4.0 | mV |
| | | | ● | | | 3.0 | | | 5.0 | mV |
| $\frac{\Delta V_{OS}}{\Delta Temp}$ | Average Offset Voltage Drift | | ● | | 2.0 | | | 5.0 | | μV/°C |
| $I_{OS}$ | Input Offset Current | (Note 4) | | | 0.1 | 0.7 | | 0.2 | 2.0 | nA |
| | | | ● | | | 1.5 | | | 3.0 | nA |
| $\frac{\Delta I_{OS}}{\Delta Temp}$ | Offset Current Drift | | ● | | 2.0 | | | 5.0 | | pA/°C |
| $I_B$ | Input Bias Current | | | | 10 | 20 | | 12 | 30 | nA |
| | | | ● | | | 30 | | | 40 | nA |
| $\frac{\Delta I_B}{\Delta Temp}$ | Bias Current Drift | | ● | | 60 | | | 90 | | pA/°C |
| $A_{VOL}$ | Large Signal Voltage Gain | $V_S = \pm 3.25V$, $I_{OUT} = 0$, $V_{OUT} = \pm 3.2V$ | | 60 | 300 | | 40 | 300 | | V/mV |
| | | | ● | 40 | | | 25 | | | V/mV |
| | | $V_S = \pm 3.25V$, $V_{OUT} = \pm 2.75V$ $I_{OUT} = \pm 10mA$ | | 10 | 25 | | 5 | 25 | | V/mV |
| | | | ● | 4 | | | 3 | | | V/mV |
| | | $I_{OUT} = \pm 2mA$, $V_{CM} = -0.4V$ $V_S = \pm 0.6V$, $V_{OUT} = \pm 0.4V$ | | 1.5 | 3.0 | | 1.0 | 3.0 | | V/mV |
| | | $V_S = \pm 0.65V$, $V_{OUT} = \pm 0.3V$ | ● | 0.5 | | | 0.75 | | | V/mV |
| | Shunt Gain (Note 5) | $0.1mA \le I_{OUT} \le 10mA$, $R_L = 500\Omega$ $1.5V \le V^+ \le 6.5V$ | | 8 | 30 | | 6 | 30 | | V/mV |
| | | | ● | 4 | | | 4 | | | V/mV |
| CMRR | Common-Mode Rejection Ratio | $V_S = \pm 3.25V$ $-3.25V \le V_{CM} \le 2.4V$ | | 89 | 102 | | 80 | 102 | | dB |
| | | $-3.25V \le V_{CM} \le 2.25V$ | ● | 83 | | | 74 | | | dB |
| PSRR | Power Supply Rejection Ratio | $-0.2V \ge V^- \ge -5.4V$ $V^+ = 1.0V$ | | 86 | 96 | | 80 | 96 | | dB |
| | | $V^+ = 1.2V$ | ● | 80 | | | 74 | | | dB |
| PSRR | | $V^- = -0.2V$ $1.0V \le V^+ \le 6.3V$ | | 94 | 106 | | 80 | 106 | | dB |
| | | $1.1V \le V^+ \le 6.3V$ | ● | 88 | | | 74 | | | dB |
| $R_{IN}$ | Input Resistance | (Note 6) | | 250 | 500 | | 150 | 400 | | kΩ |
| | | | ● | 150 | | | 115 | | | kΩ |
| $I_S$ | Supply Current | | | | 260 | 400 | | 280 | 500 | μA |
| | | | ● | | | 500 | | | 570 | μA |

# REFERENCE AMPLIFIER ELECTRICAL CHARACTERISTICS (Note 3)

| SYMBOL | PARAMETER | CONDITIONS | | LM10BL MIN | LM10BL TYP | LM10BL MAX | LM10CL MIN | LM10CL TYP | LM10CL MAX | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|
| $V_{REF}$ | Feedback Sense Voltage | Voltage at Pin 1 with Pin 1 Connected to Pin 8 | | 195 | 200 | 205 | 190 | 200 | 210 | mV |
| | | | ● | 194 | 200 | 206 | 189 | 200 | 211 | mV |
| $\frac{\Delta V_{REF}}{\Delta Temp}$ | Reference Drift | | ● | | 0.002 | | | 0.003 | | %/°C |
| | Feedback Current | Current into Pin 8 | | | 20 | 50 | | 22 | 75 | nA |
| | | | ● | | | 65 | | | 90 | nA |
| | Line Regulation | $0 \le I_{REF} \le 0.5mA$, $V_{REF} = 200mV$ $1.2V \le V_S \le 6.5V$ | | | 0.001 | 0.01 | | 0.001 | 0.02 | %/V |
| | | $1.3V \le V_S \le 6.5V$ | ● | | 0.001 | 0.02 | | 0.001 | 0.03 | %/V |
| | Load Regulation | $0 \le I_{REF} \le 0.5mA$ $V^+ - V_{REF} \ge 1.0V$ | | | 0.01 | 0.1 | | 0.01 | 0.15 | % |
| | | $V^+ - V_{REF} \ge 1.1V$ | ● | | 0.01 | 0.15 | | 0.01 | 0.20 | % |
| | Reference Amplifier Gain | $0.2V \le V_{REF} \le 5.5V$ | | 30 | 70 | | 20 | 70 | | V/mV |
| | | | ● | 20 | | | 15 | | | V/mV |

The ● denotes the specifications which apply over full operating temperature range.

**Note 1:** The input voltage can exceed the supply voltages as long as the voltage from the input to any other terminal does not exceed the maximum differential voltage, and the maximum junction temperature is not exceeded due to the excess power dissipation that occurs when the input voltage is less than the negative supply voltage.

**Note 2:** The maximum operating junction temperatures are: 150°C for the LM10; 100°C for the LM10B and LM10BL; and 85°C for the LM10C and LM10CL. Package derating factors will be found on the back page of this data sheet.

**Note 3:** These specifications apply for the following conditions unless otherwise noted:

| | at 25°C | over temperature |
|---|---|---|
| (a) | $V^- \le V_{CM} \le V^+ - 0.85V$ | $V^- \le V_{CM} \le V^+ - 1.0V$ |
| (b) | $1.2V \le V_S \le V_{MAX}$ | $1.3V \le V_S \le V_{MAX}$ |

$V_{REF} = 0.2V$ and $0 \le I_{REF} \le 1.0mA$ where $V_{MAX} = 40V$ for the LM10, LM10B and LM10C and $V_{MAX} = 6.5V$ for the LM10BL and LM10CL. The specifications do not include errors due to thermal gradients ($\tau_1 \approx 20ms$), die heating ($\tau_2 \approx 0.2$ sec) or package heating.

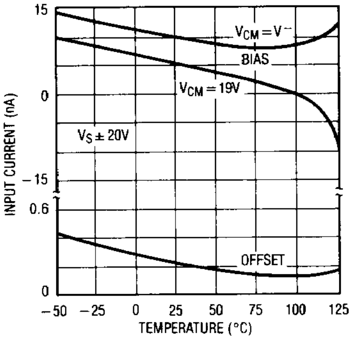
**Note 4:** For $T_J > 90°C$, $I_{OS}$ may exceed 1.5nA when $V_{CM} = V^-$. When the common-mode input voltage is within 100mV of the negative supply and $T_J = 125°C$, the offset current will be less than 5nA.

**Note 5:** Shunt gain defines the operation in floating applications when the output is connected to the $V^+$ terminal and input common-mode is referred to $V^-$ (see typical applications). The effects of larger output voltage swing with higher load resistance can be accounted for by adding the positive supply rejection error.

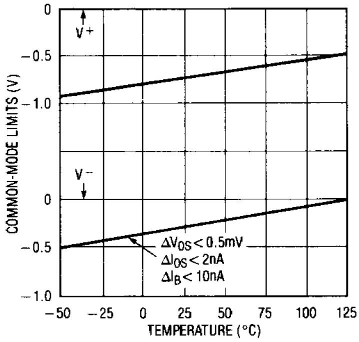
**Note 6:** Guaranteed by design.

# TYPICAL PERFORMANCE CHARACTERISTICS (Op Amp)

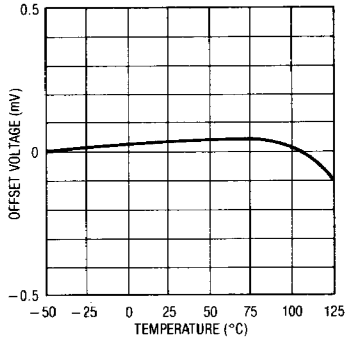
### Input Current



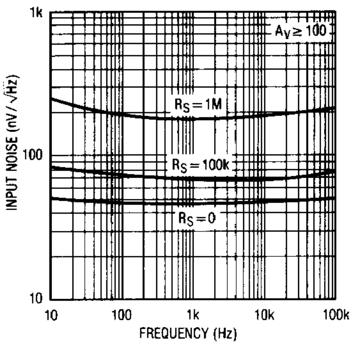

### Common-Mode Limits



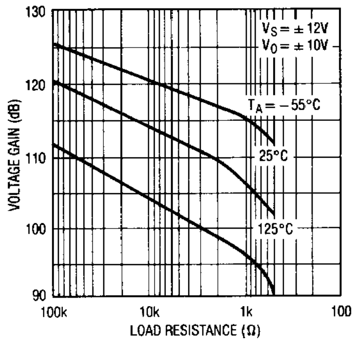

### Offset Voltage Drift



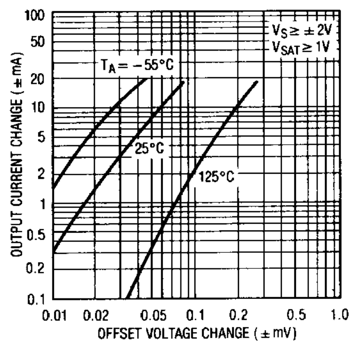

### Input Noise Voltage



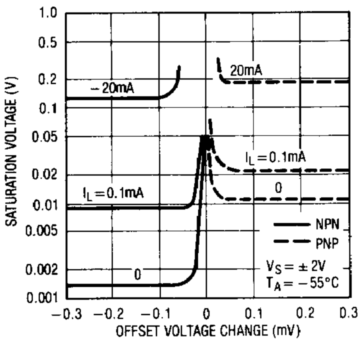

### DC Voltage Gain



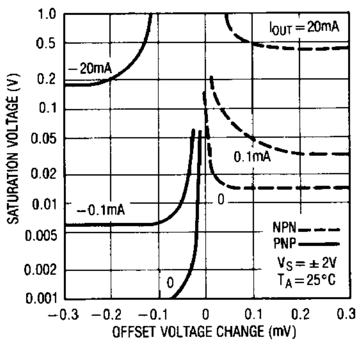

### Transconductance



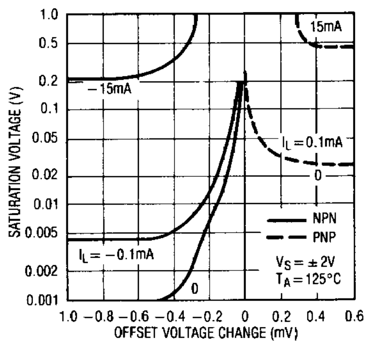

### Output Saturation Characteristics




### Output Saturation Characteristics

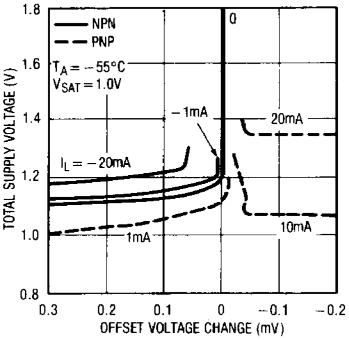



### Output Saturation Characteristics

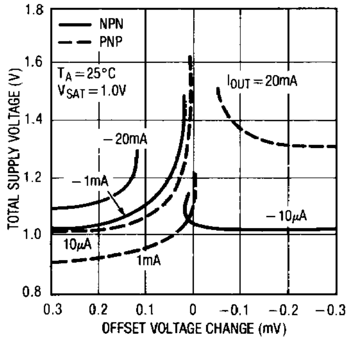


## TYPICAL PERFORMANCE CHARACTERISTICS (Op Amp)

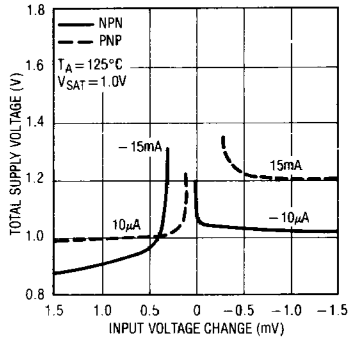
### Minimum Supply Voltage




### Minimum Supply Voltage

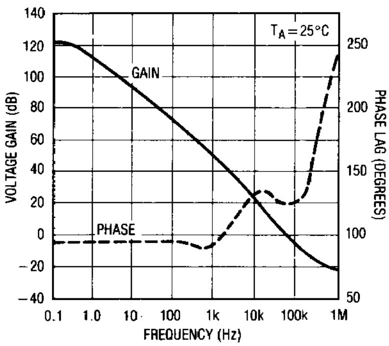



### Minimum Supply Voltage

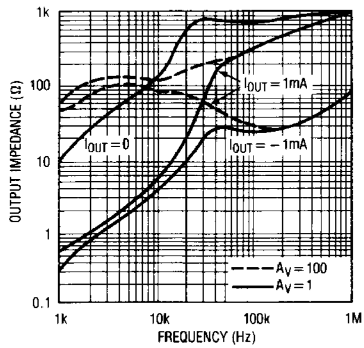




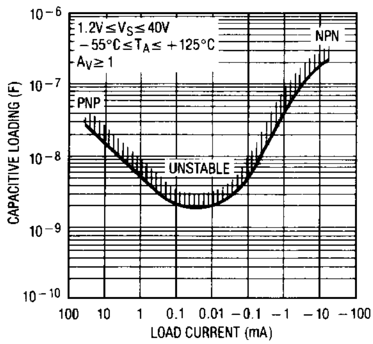

### Frequency Response



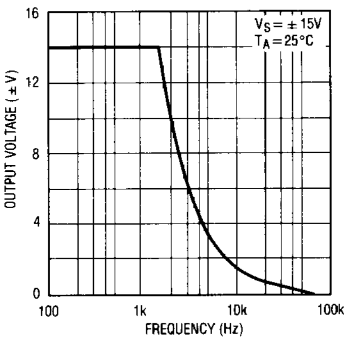

### Output Impedance



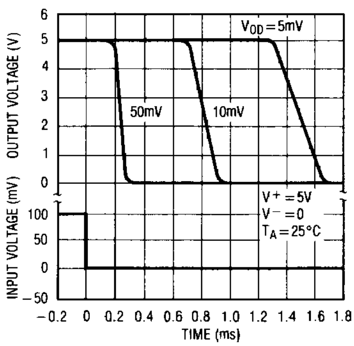

### Typical Stability Range



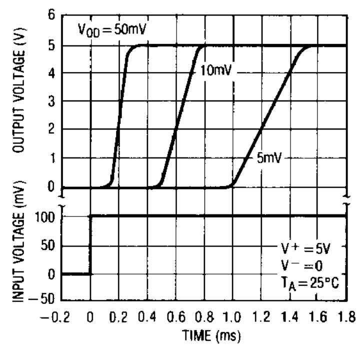

### Large Signal Response




### Comparator Response Time for Various Input Overdrives

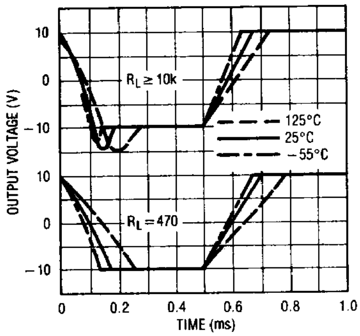



### Comparator Response Time for Various Input Overdrives

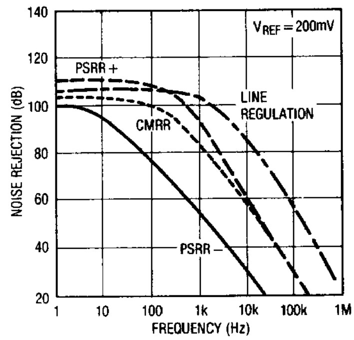


# TYPICAL PERFORMANCE CHARACTERISTICS

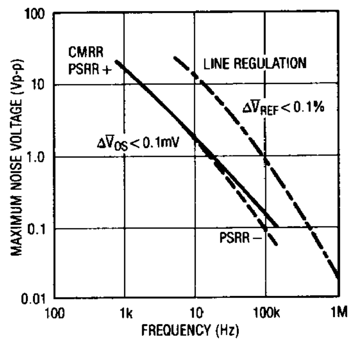
### Follower Pulse Response



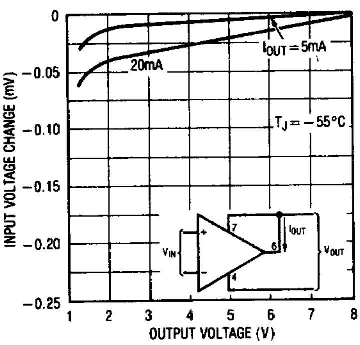

### Noise Rejection



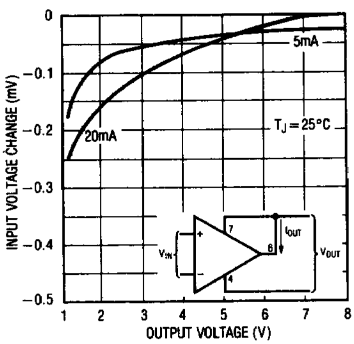

### Rejection Slew Limiting



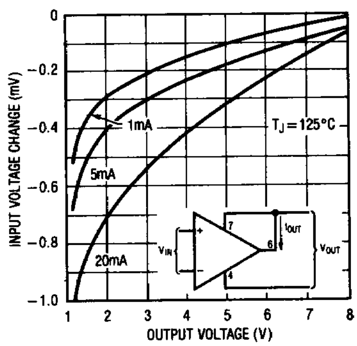

### Shunt Gain



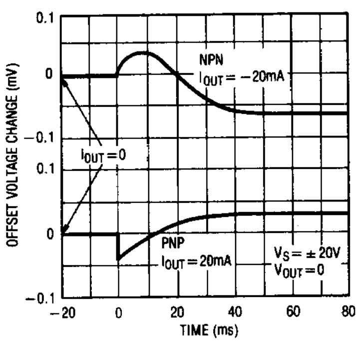

### Shunt Gain



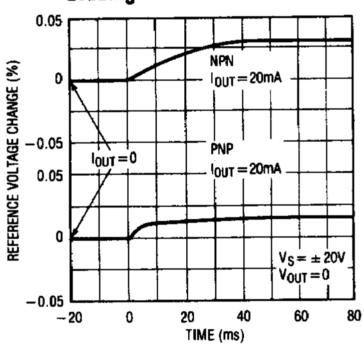

### Shunt Gain




### Thermal Gradient Feedback

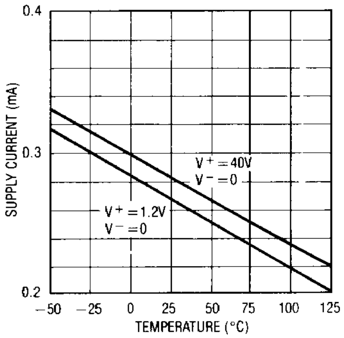



### Change in Reference Op Amp Loading

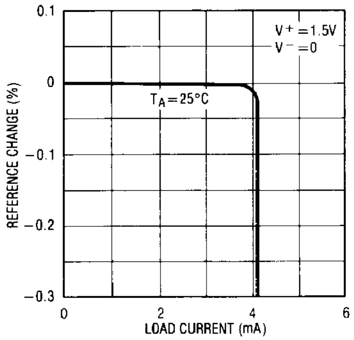


# TYPICAL PERFORMANCE CHARACTERISTICS (Reference)

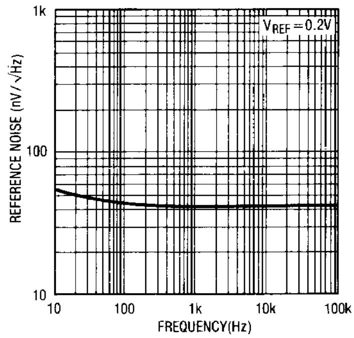
### Supply Current



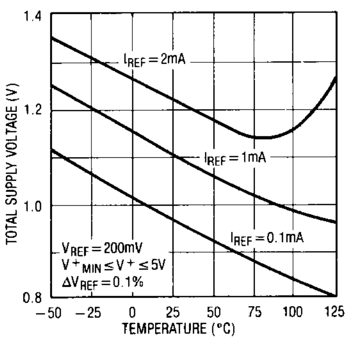

### Load Regulation



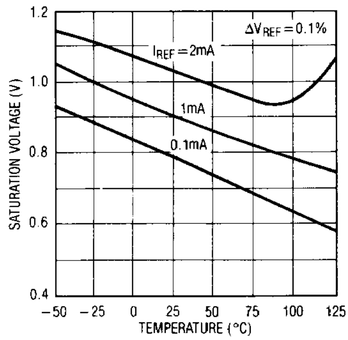

### Reference Noise Voltage



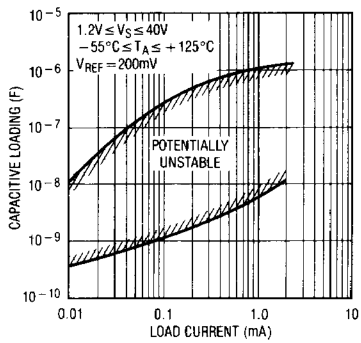

### Minimum Supply Voltage



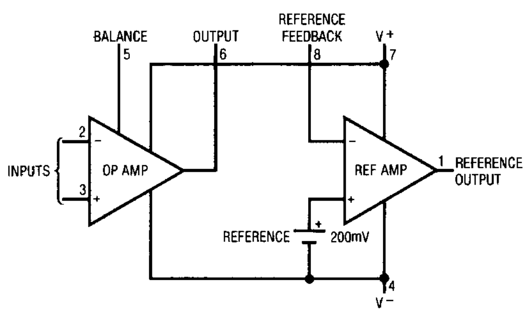

### Output Saturation




### Typical Stability Range




# BLOCK DIAGRAM

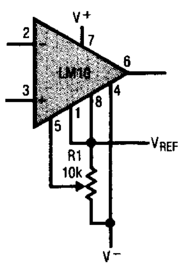


## APPLICATION HINTS

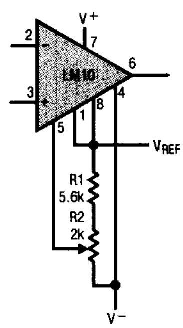
With heavy amplifier loading to $V^-$, resistance drops in the $V^-$ lead can adversely affect reference regulation. Lead resistance can approach 1Ω. Therefore, the common to the reference circuitry should be connected as close as possible to the package.

## TYPICAL APPLICATIONS

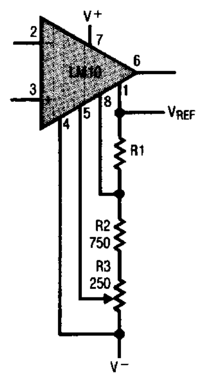
**Standard Offset Adjustment**



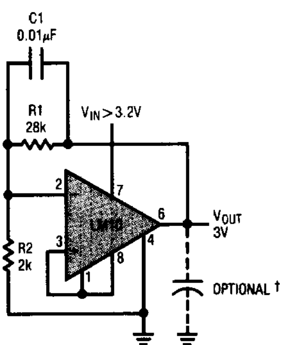

**Limited Range Offset Adjustment**




**Limited Range Offset Adjustment with Boosted Reference**

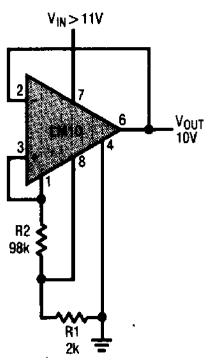



**Low Voltage Regulator**

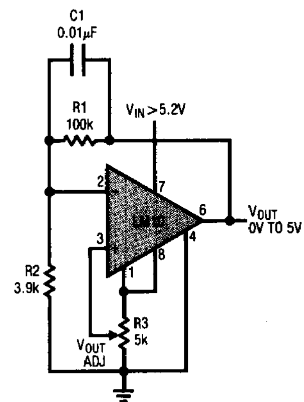



† USE ELECTROLYTIC OUTPUT CAPACITORS

**Best Regulation**

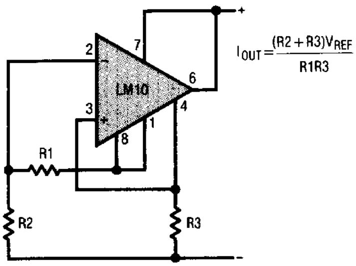



**0V to 5V Regulator**

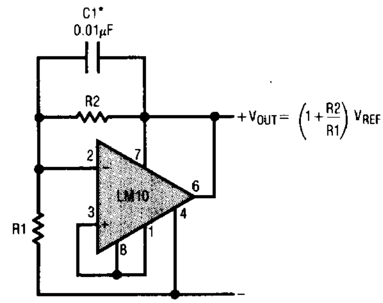


# TYPICAL APPLICATIONS

### Two-Terminal Current Regulator

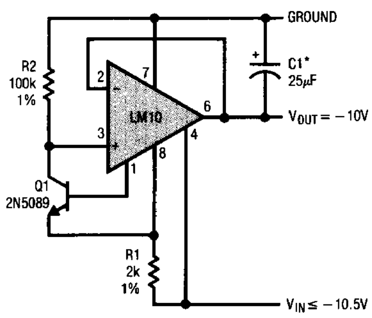



### Shunt Regulator



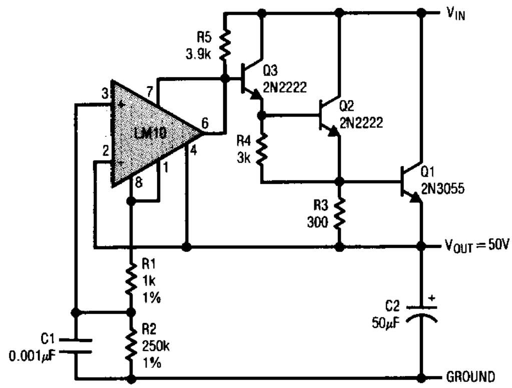

*REQUIRED FOR CAPACITIVE LOADING

### Negative Regulator



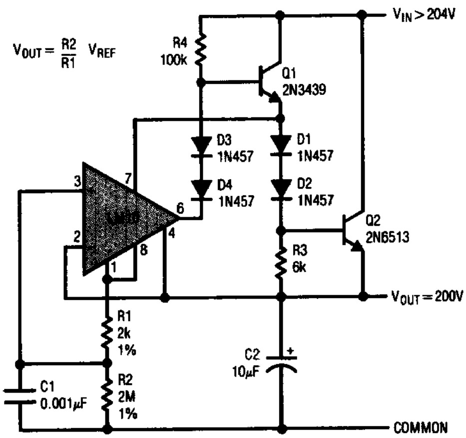

*ELECTROLYTIC

### Floating Regulator

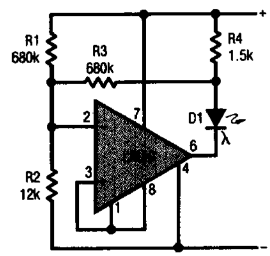


# TYPICAL APPLICATIONS

## High Voltage Regulator

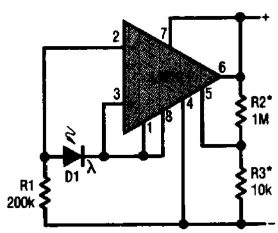



## 6V Battery-Level Indicator



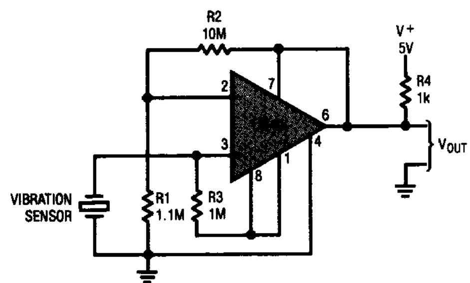

LED DIMS BELOW 7V

## Light Level Sensor



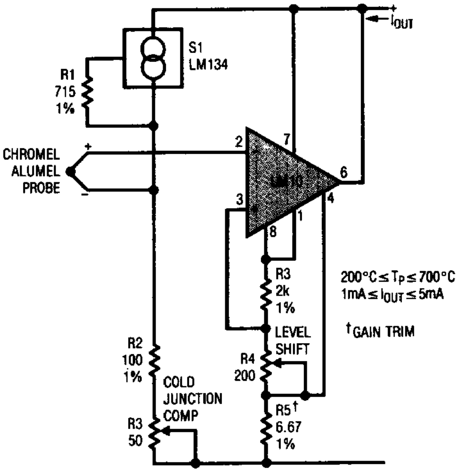

*PROVIDES HYSTERESIS

## Transducer Amplifier

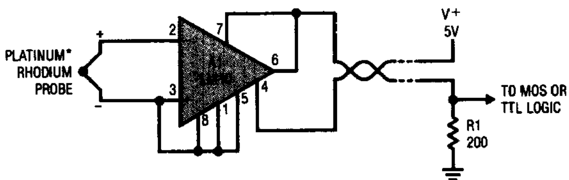


# TYPICAL APPLICATIONS

## Thermocouple Transmitter

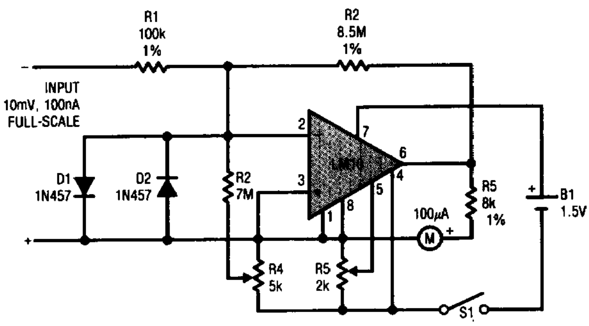



## Flame Detector

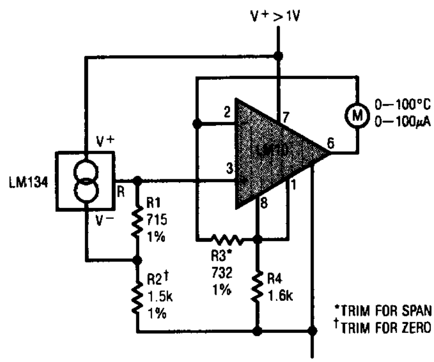



*800°C THRESHOLD IS ESTABLISHED BY CONNECTING BALANCE TO $V_{REF}$

## Meter Amplifier

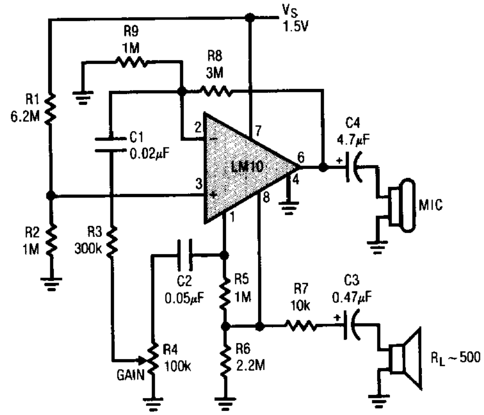



## Thermometer

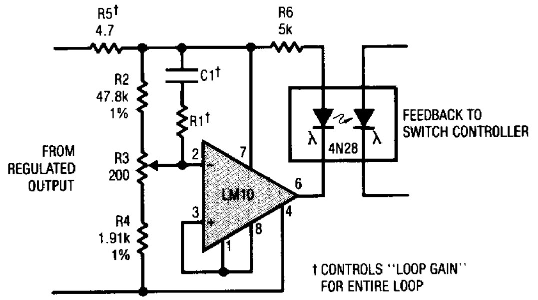


## TYPICAL APPLICATIONS

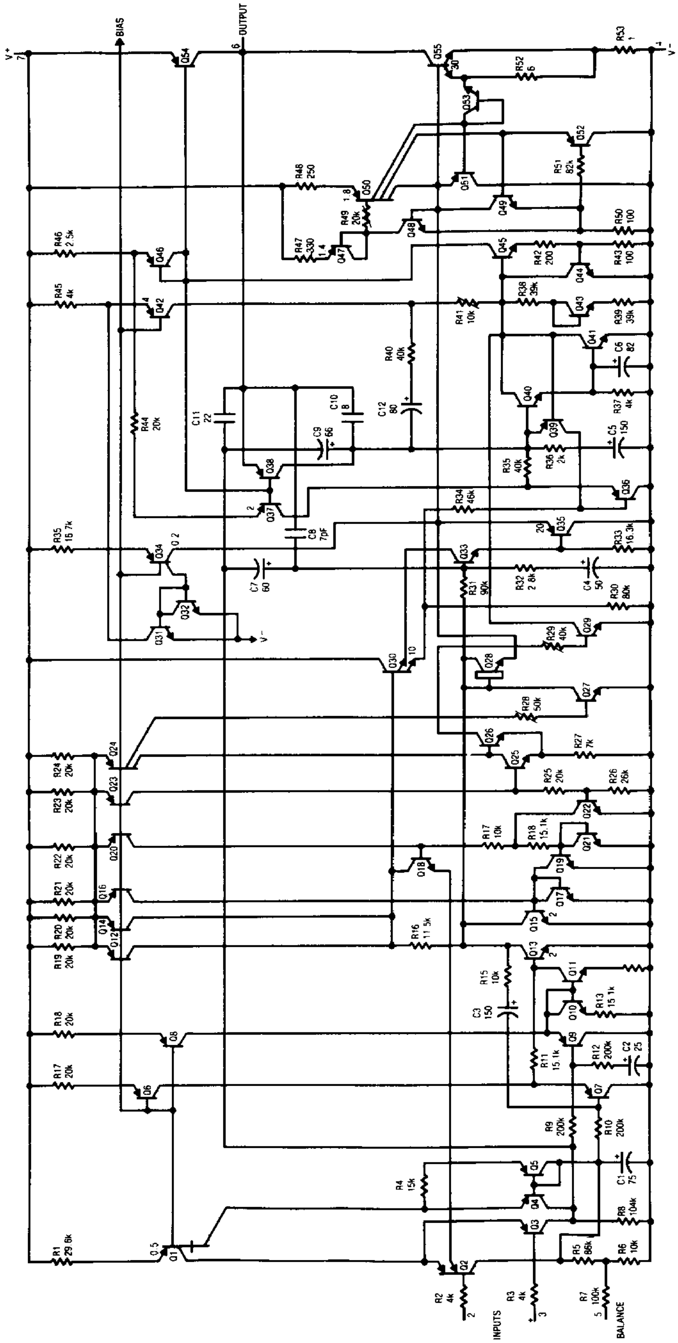
**Microphone Amplifier**
**$A_V \approx 1k$**




**Isolated Voltage Sensor**
**for Switching Regulators**

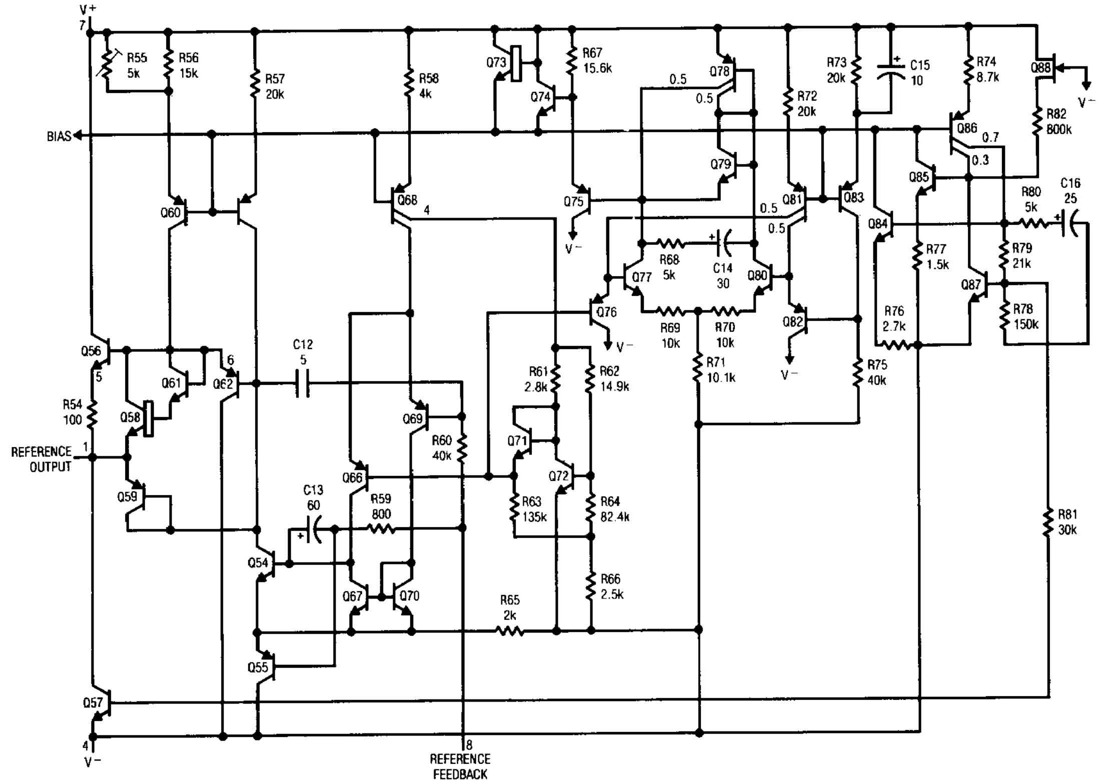


# OP AMP SCHEMATIC DIAGRAM



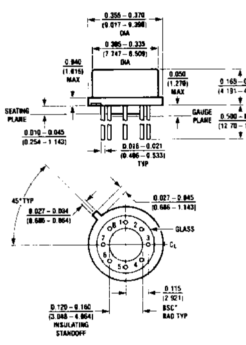

2

## REFERENCE AND INTERNAL REGULATOR SCHEMATIC DIAGRAM




## PACKAGE DESCRIPTION

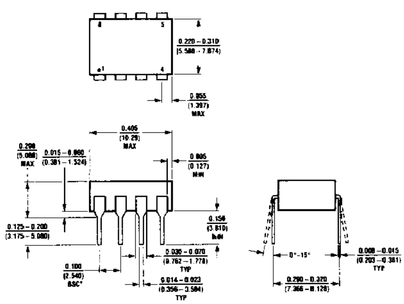
### H Package
### Metal Can



NOTE: DIMENSIONS IN INCHES

| $T_j$max | $\theta_{ja}$ | $\theta_{jc}$ |
|---|---|---|
| 150°C | 150°C/W | 45°C/W |

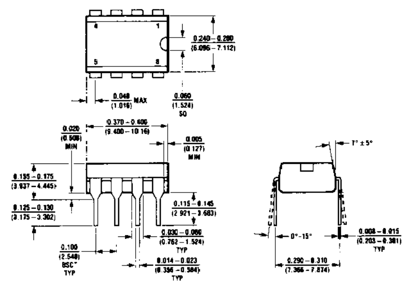
### J8 Package
### 8 Lead Hermetic Dip



NOTE: DIMENSIONS IN INCHES UNLESS OTHERWISE NOTED
*LEADS WITHIN 0.007 OF TRUE POSITION (TP) AT GAUGE PLANE

| $T_j$max | $\theta_{ja}$ |
|---|---|
| 150°C | 100°C/W |

### N8 Package
### 8 Lead Plastic



NOTE: DIMENSIONS IN INCHES UNLESS OTHERWISE NOTED
*LEADS WITHIN 0.007 OF TRUE POSITION (TP) AT GAUGE PLANE

| $T_j$max | $\theta_{ja}$ |
|---|---|
| 100°C | 130°C/W |