*National Semiconductor*

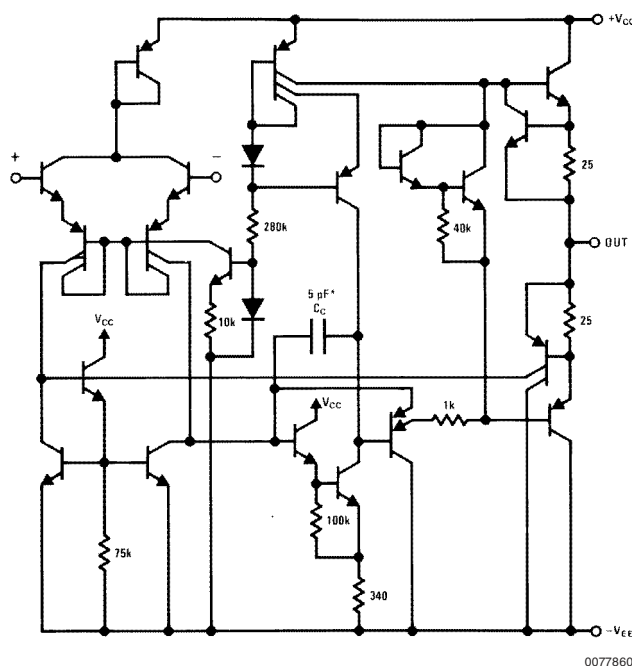# LM148/LM248/LM348
# Quad 741 Op Amps

## General Description

The LM148 series is a true quad 741. It consists of four independent, high gain, internally compensated, low power operational amplifiers which have been designed to provide functional characteristics identical to those of the familiar 741 operational amplifier. In addition the total supply current for all four amplifiers is comparable to the supply current of a single 741 type op amp. Other features include input offset currents and input bias current which are much less than those of a standard 741. Also, excellent isolation between amplifiers has been achieved by independently biasing each amplifier and using layout techniques which minimize thermal coupling.

The LM148 can be used anywhere multiple 741 or 1558 type amplifiers are being used and in applications where amplifier matching or high packing density is required. For lower power refer to LF444.

## Features

- 741 op amp operating characteristics
- Class AB output stage — no crossover distortion
- Pin compatible with the LM124
- Overload protection for inputs and outputs
- Low supply current drain: 0.6 mA/Amplifier
- Low input offset voltage: 1 mV
- Low input offset current: 4 nA
- Low input bias current 30 nA
- High degree of isolation between amplifiers: 120 dB
- Gain bandwidth product
- LM148 (unity gain): 1.0 MHz

## Schematic Diagram



* 1 pF in the LM149

00778601

# Absolute Maximum Ratings (Note 4)

**Distributors for availability and specifications.**

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/**

| | LM148 | LM248 | LM348 |
|---|---|---|---|
| Supply Voltage | ±22V | ±18V | ±18V |
| Differential Input Voltage | ±44V | ±36V | ±36V |
| Output Short Circuit Duration (Note 1) | Continuous | Continuous | Continuous |
| Power Dissipation (P$_d$ at 25˚C) and | | | |
| Thermal Resistance ($\theta_{jA}$), (Note 2) | | | |
| Molded DIP (N) P$_d$ | — | — | 750 mW |
| $\theta_{jA}$ | — | — | 100˚C/W |
| Cavity DIP (J) P$_d$ | 1100 mW | 800 mW | 700 mW |
| $\theta_{JA}$ | 110˚C/W | 110˚C/W | 110˚C/W |
| Maximum Junction Temperature (T$_{jMAX}$) | 150˚C | 110˚C | 100˚C |
| Operating Temperature Range | $-55˚C \leq T_A \leq +125˚C$ | $-25˚C \leq T_A \leq +85˚C$ | $0˚C \leq T_A \leq +70˚C$ |
| Storage Temperature Range | −65˚C to +150˚C | −65˚C to +150˚C | −65˚C to +150˚C |
| Lead Temperature (Soldering, 10 sec.) Ceramic | 300˚C | 300˚C | 300˚C |
| Lead Temperature (Soldering, 10 sec.) Plastic | | | 260˚C |
| Soldering Information | | | |
| Dual-In-Line Package | | | |
| Soldering (10 seconds) | 260˚C | 260˚C | 260˚C |
| Small Outline Package | | | |
| Vapor Phase (60 seconds) | 215˚C | 215˚C | 215˚C |
| Infrared (15 seconds) | 220˚C | 220˚C | 220˚C |

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount

devices.

| | | | |
|---|---|---|---|
| ESD tolerance (Note 5) | 500V | 500V | 500V |

## Electrical Characteristics

(Note 3)

| Parameter | Conditions | LM148 | | | LM248 | | | LM348 | | | Units |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Typ | Max | Min | Typ | Max | Min | Typ | Max | |
| Input Offset Voltage | $T_A$ = 25˚C, $R_S \leq$ 10 kΩ | | 1.0 | 5.0 | | 1.0 | 6.0 | | 1.0 | 6.0 | mV |
| Input Offset Current | $T_A$ = 25˚C | | 4 | 25 | | 4 | 50 | | 4 | 50 | nA |
| Input Bias Current | $T_A$ = 25˚C | | 30 | 100 | | 30 | 200 | | 30 | 200 | nA |
| Input Resistance | $T_A$ = 25˚C | 0.8 | 2.5 | | 0.8 | 2.5 | | 0.8 | 2.5 | | MΩ |
| Supply Current All Amplifiers | $T_A$ = 25˚C, $V_S$ = ±15V | | 2.4 | 3.6 | | 2.4 | 4.5 | | 2.4 | 4.5 | mA |
| Large Signal Voltage Gain | $T_A$ = 25˚C, $V_S$ = ±15V $V_{OUT}$ = ±10V, $R_L \geq$ 2 kΩ | 50 | 160 | | 25 | 160 | | 25 | 160 | | V/mV |
| Amplifier to Amplifier Coupling | $T_A$ = 25˚C, f = 1 Hz to 20 kHz (Input Referred) See Crosstalk Test Circuit | | −120 | | | −120 | | | −120 | | dB |
| Small Signal Bandwidth | $T_A$ = 25˚C, LM148 Series | | 1.0 | | | 1.0 | | | 1.0 | | MHz |
| Phase Margin | $T_A$ = 25˚C, LM148 Series ($A_V$ = 1) | | 60 | | | 60 | | | 60 | | degrees |
| Slew Rate | $T_A$ = 25˚C, LM148 Series ($A_V$ = 1) | | 0.5 | | | 0.5 | | | 0.5 | | V/µs |
| Output Short Circuit Current | $T_A$ = 25˚C | | 25 | | | 25 | | | 25 | | mA |
| Input Offset Voltage | $R_S \leq$ 10 kΩ | | | 6.0 | | | 7.5 | | | 7.5 | mV |
| Input Offset Current | | | | 75 | | | 125 | | | 100 | nA |

# Electrical Characteristics (Continued)

(Note 3)

| Parameter | Conditions | LM148 | | | LM248 | | | LM348 | | | Units |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Typ | Max | Min | Typ | Max | Min | Typ | Max | |
| Input Bias Current | | | | 325 | | | 500 | | | 400 | nA |
| Large Signal Voltage Gain | $V_S = \pm15V$, $V_{OUT} = \pm10V$, $R_L > 2\ k\Omega$ | 25 | | | 15 | | | 15 | | | V/mV |
| Output Voltage Swing | $V_S = \pm15V$, $R_L = 10\ k\Omega$ | ±12 | ±13 | | ±12 | ±13 | | ±12 | ±13 | | V |
| | $R_L = 2\ k\Omega$ | ±10 | ±12 | | ±10 | ±12 | | ±10 | ±12 | | V |
| Input Voltage Range | $V_S = \pm15V$ | ±12 | | | ±12 | | | ±12 | | | V |
| Common-Mode Rejection Ratio | $R_S \leq 10\ k\Omega$ | 70 | 90 | | 70 | 90 | | 70 | 90 | | dB |
| Supply Voltage Rejection | $R_S \leq 10\ k\Omega$, $\pm5V \leq V_S \leq \pm15V$ | 77 | 96 | | 77 | 96 | | 77 | 96 | | dB |

**Note 1:** Any of the amplifier outputs can be shorted to ground indefinitely; however, more than one should not be simultaneously shorted as the maximum junction temperature will be exceeded.

**Note 2:** The maximum power dissipation for these devices must be derated at elevated temperatures and is dicated by $T_{JMAX}$, $\theta_{JA}$, and the ambient temperature, $T_A$. The maximum available power dissipation at any temperature is $P_d = (T_{JMAX} - T_A)/\theta_{JA}$ or the 25˚C $P_{DMAX}$, whichever is less.

**Note 3:** These specifications apply for $V_S = \pm15V$ and over the absolute maximum operating temperature range ($T_L \leq T_A \leq T_H$) unless otherwise noted.
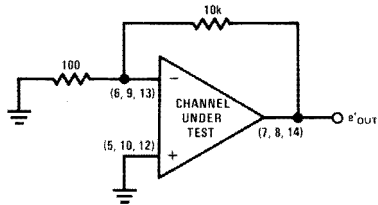
**Note 4:** Refer to RETS 148X for LM148 military specifications.
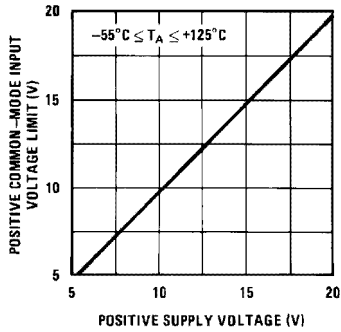
**Note 5:** Human body model, 1.5 $k\Omega$ in series with 100 pF.
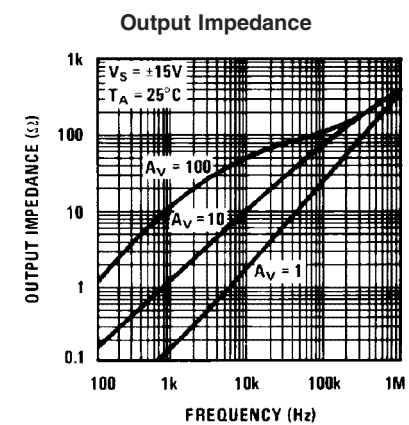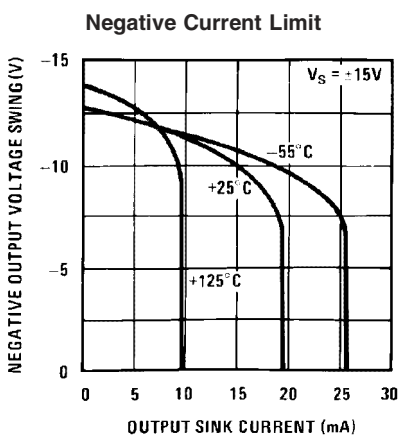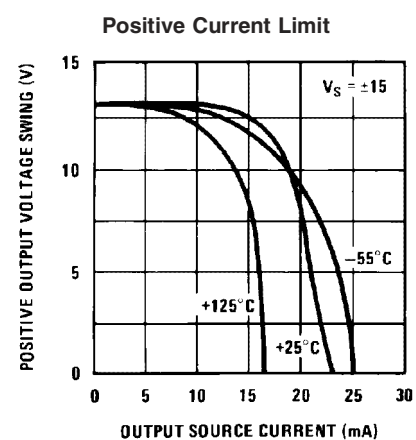
# Cross Talk Test Circuit $V_S = \pm15V$
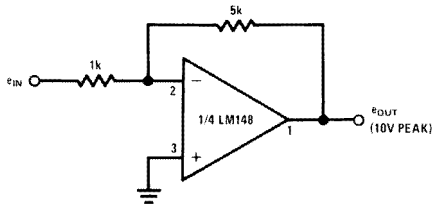


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# Typical Performance Characteristics

### Supply Current



00778623

### Input Bias Current



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### Voltage Swing



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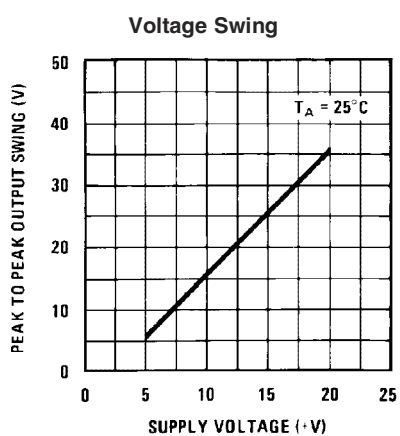### Positive Current Limit



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### Negative Current Limit



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### Output Impedance
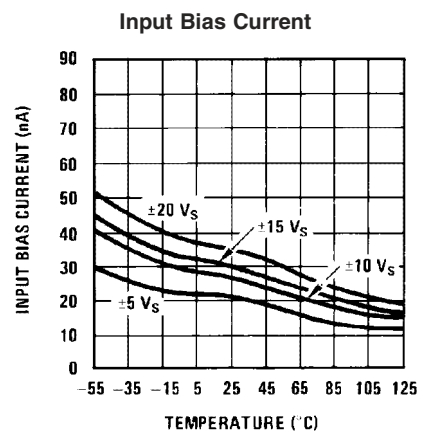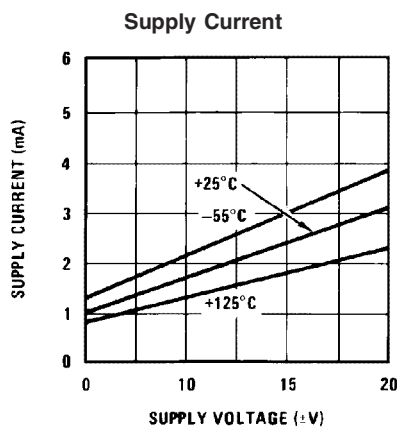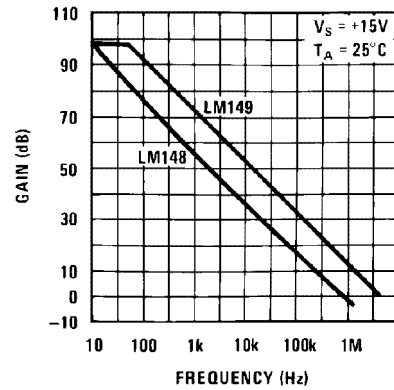


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# Typical Performance Characteristics (Continued)
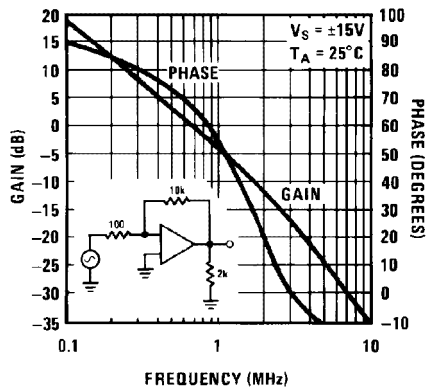
**Common-Mode Rejection Ratio**
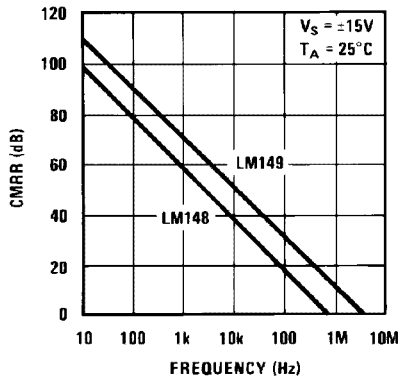


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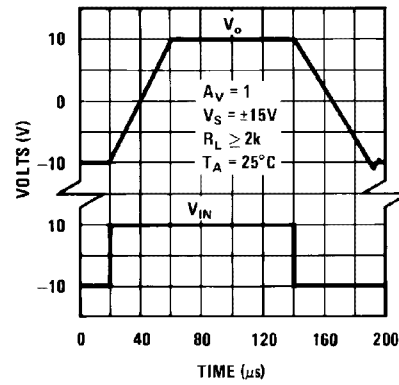
**Open Loop Frequency Response**
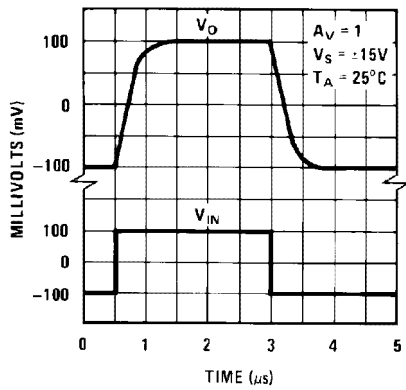


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**Bode Plot LM148**



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**Large Signal Pulse Response (LM148)**



00778633

**Small Signal Pulse Response (LM148)**



00778635

**Undistorted Output Voltage Swing**
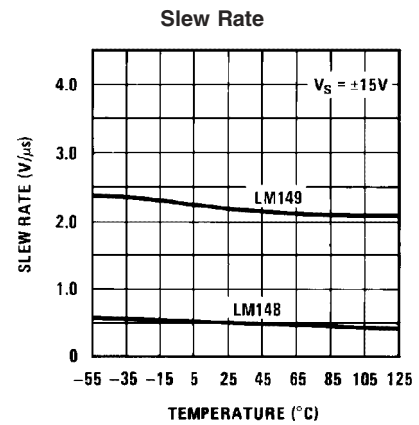


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## Typical Performance Characteristics (Continued)
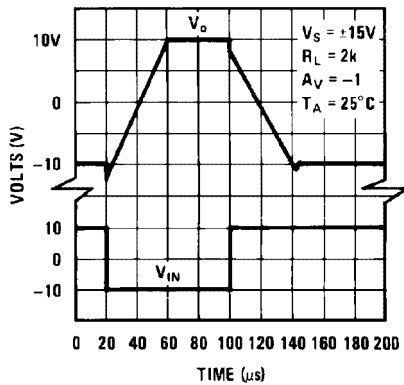
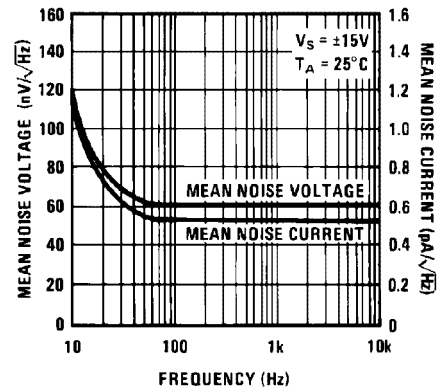**Gain Bandwidth**



00778638

**Slew Rate**
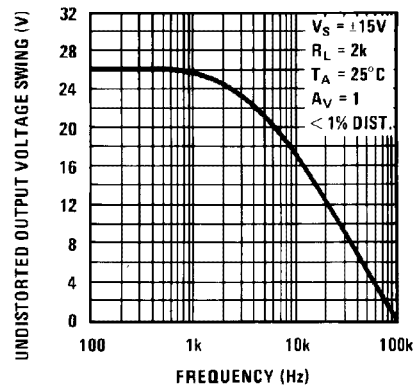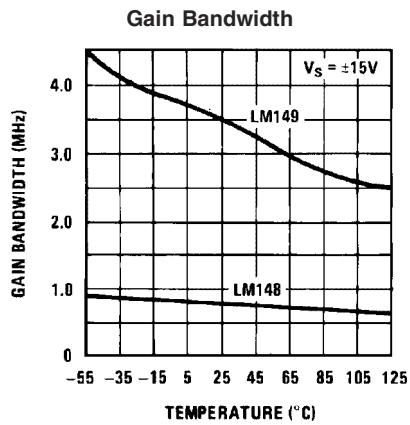


00778639

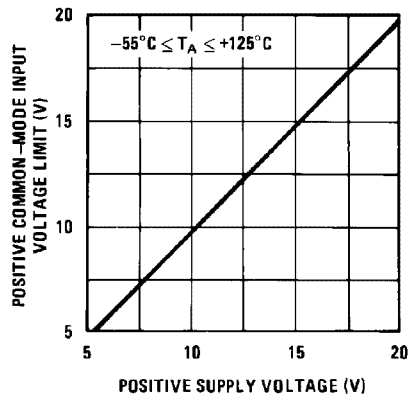**Inverting Large Signal Pulse Response (LM148)**



00778641

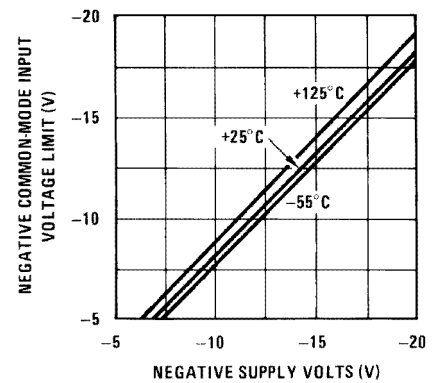**Input Noise Voltage and Noise Current**



00778642

**Positive Common-Mode Input Voltage Limit**



00778643

**Negative Common-Mode Input Voltage Limit**



00778605

# Application Hints

The LM148 series are quad low power 741 op amps. In the proliferation of quad op amps, these are the first to offer the convenience of familiar, easy to use operating characteristics of the 741 op amp. In those applications where 741 op amps have been employed, the LM148 series op amps can be employed directly with no change in circuit performance.

The package pin-outs are such that the inverting input of each amplifier is adjacent to its output. In addition, the amplifier outputs are located in the corners of the package which simplifies PC board layout and minimizes package related capacitive coupling between amplifiers.

The input characteristics of these amplifiers allow differential input voltages which can exceed the supply voltages. In addition, if either of the input voltages is within the operating common-mode range, the phase of the output remains correct. If the negative limit of the operating common-mode range is exceeded at both inputs, the output voltage will be positive. For input voltages which greatly exceed the maximum supply voltages, either differentially or common-mode, resistors should be placed in series with the inputs to limit the current.

Like the LM741, these amplifiers can easily drive a 100 pF capacitive load throughout the entire dynamic output voltage and current range. However, if very large capacitive loads must be driven by a non-inverting unity gain amplifier, a resistor should be placed between the output (and feedback connection) and the capacitance to reduce the phase shift resulting from the capacitive loading.

The output current of each amplifier in the package is limited. Short circuits from an output to either ground or the power supplies will not destroy the unit. However, if multiple output shorts occur simultaneously, the time duration should be short to prevent the unit from being destroyed as a result of excessive power dissipation in the IC chip.

As with most amplifiers, care should be taken lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize "pickup" and maximize the frequency of the feedback pole which capacitance from the input to ground creates.

A feedback pole is created when the feedback around any amplifier is resistive. The parallel resistance and capacitance from the input of the device (usually the inverting input) to AC ground set the frequency of the pole. In many instances the frequency of this pole is much greater than the expected 3 dB frequency of the closed loop gain and consequently there is negligible effect on stability margin. However, if the feedback pole is less than approximately six times the expected 3 dB frequency a lead capacitor should be placed from the output to the input of the op amp. The value of the added capacitor should be such that the RC time constant of this capacitor and the resistance it parallels is greater than or equal to the original feedback pole time constant.

# Typical Applications—LM148

**One Decade Low Distortion Sinewave Generator**
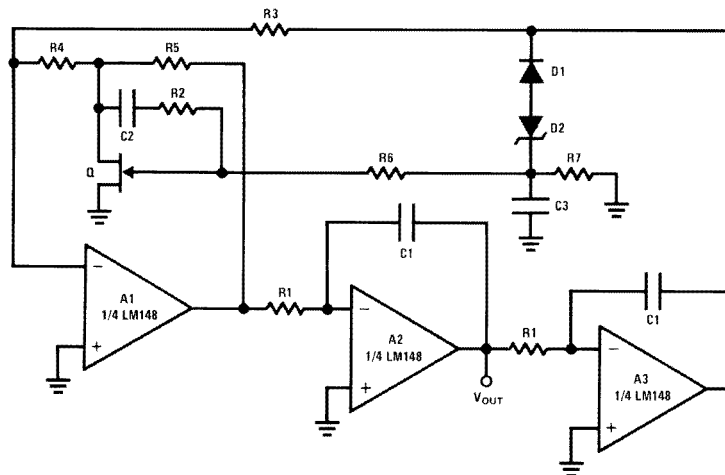


00778608

$$f = \frac{1}{2\pi R1C1} \times \sqrt{K}, \quad K = \frac{R4R5}{R3}\left(\frac{1}{r_{DS}} + \frac{1}{R4} + \frac{1}{R5}\right), \quad r_{DS} \approx \frac{R_{ON}}{\left(1 - \frac{V_{GS}}{V_P}\right)^{1/2}}$$

$f_{MAX}$ = 5 kHz, THD ≤ 0.03%

R1 = 100k pot. C1 = 0.0047 μF, C2 = 0.01 μF, C3 = 0.1 μF, R2 = R6 = R7 = 1M,

R3 = 5.1k, R4 = 12Ω, R5 = 240Ω, Q = NS5102, D1 = 1N914, D2 = 3.6V avalanche

diode (ex. LM103), $V_S$ = ±15V

A simpler version with some distortion degradation at high frequencies can be made by using A1 as a simple inverting amplifier, and by putting back to back zeners in the feedback loop of A3.

# Typical Applications—LM148 (Continued)
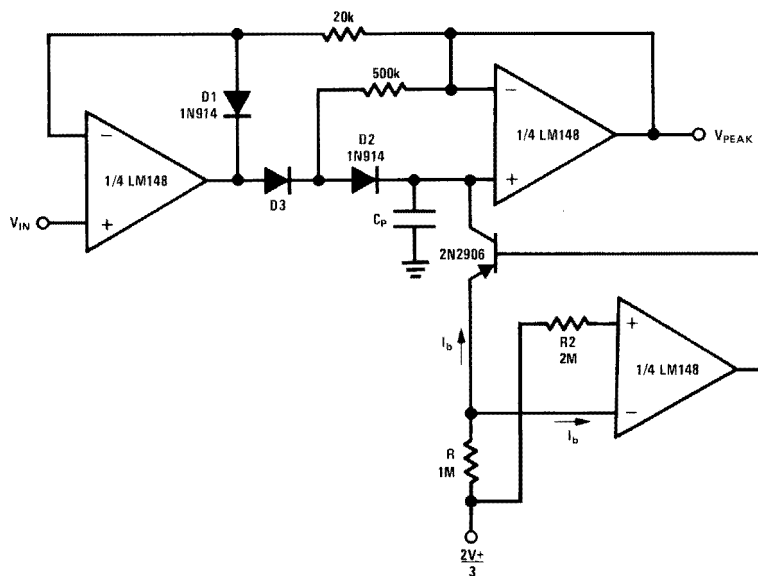
**Low Cost Instrumentation Amplifier**
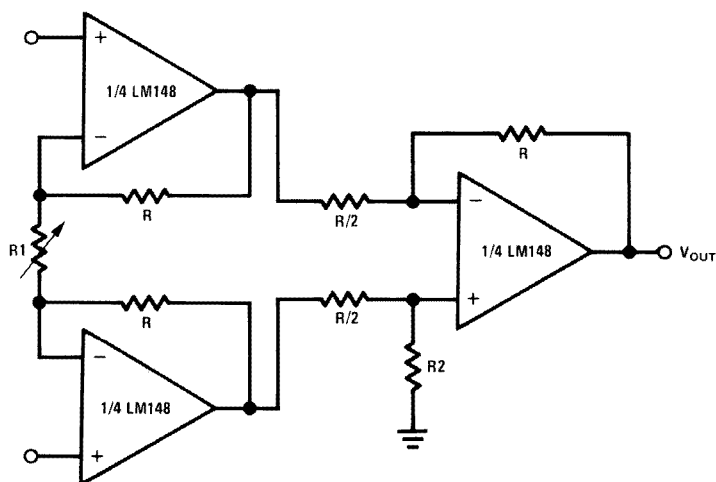


00778609

$$V_{OUT} = 2\left(\frac{2R}{R1} + 1\right), \, V_S^- - 3V \leq V_{IN\,CM} \leq V_S^+ - 3V,$$

$V_S = \pm 15V$

R = R2, trim R2 to boost CMRR

**Low Drift Peak Detector with Bias Current Compensation**



00778610
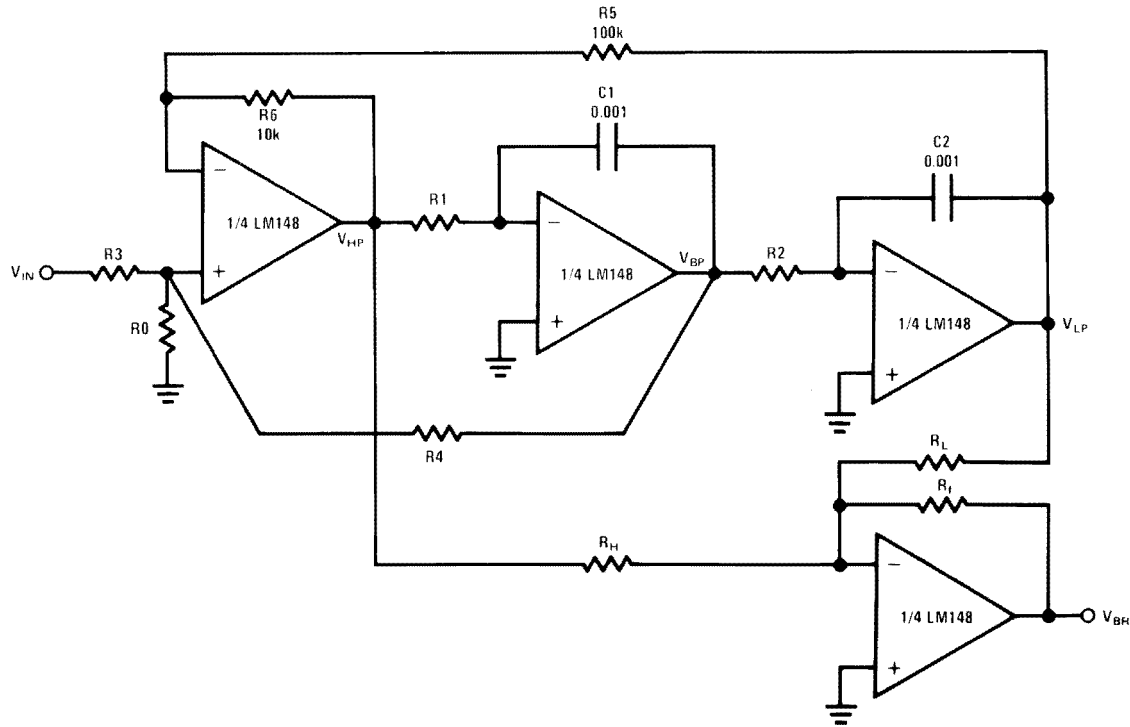
Adjust R for minimum drift

D3 low leakage diode

D1 added to improve speed

$V_S = \pm 15V$

## Typical Applications—**LM148** (Continued)

### Universal State-Variable Filter



00778611

Tune Q through R0,

For predictable results: $f_O\, Q \leq 4 \times 10^4$

Use Band Pass output to tune for Q

$$\frac{V_{(s)}}{V_{IN(s)}} = \frac{N_{(s)}}{D_{(s)}}, \; D_{(s)} = S^2 + \frac{S\omega_0}{Q} + \omega_o{}^2$$

$$N_{HP(s)} = S^2\, H_{OHP}, \; N_{BP(s)} = \frac{-s\omega_0\, H_{OBP}}{Q} \;\; N_{LP} = \omega_o{}^2\, H_{OLP}.$$

$$f_o = \frac{1}{2\pi} \sqrt{\frac{R6}{R5}} \sqrt{\frac{1}{t1\,t2}}, \; t_i = R_i C_i, \; Q = \left( \frac{1 + R4|R3 + R4|R0}{1 + R6|R5} \right)\left( \frac{R6}{R5}\frac{t_1}{t_2} \right)^{1/2}$$

$$f_{NOTCH} = \frac{1}{2\pi} \left( \frac{R_H}{R_L\, t_1\, t_2} \right)^{1/2}, \; H_{OHP} = \frac{1 + R6|R5}{1 + R3|R0 + R3|R4}, \; H_{OBP} = \frac{1 + R4|R3 + R4|R0}{1 + R3|R0 + R3|R4}$$

$$H_{OLP} = \frac{1 + R5|R6}{1 + R3|R0 + R3|R4}$$

# Typical Applications — LM148 (Continued)

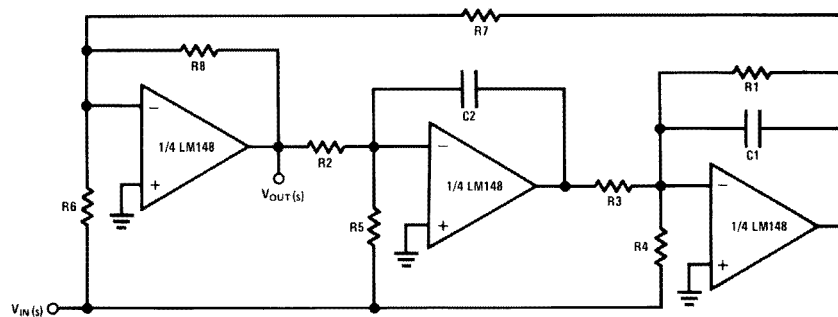### A 1 kHz 4 Pole Butterworth
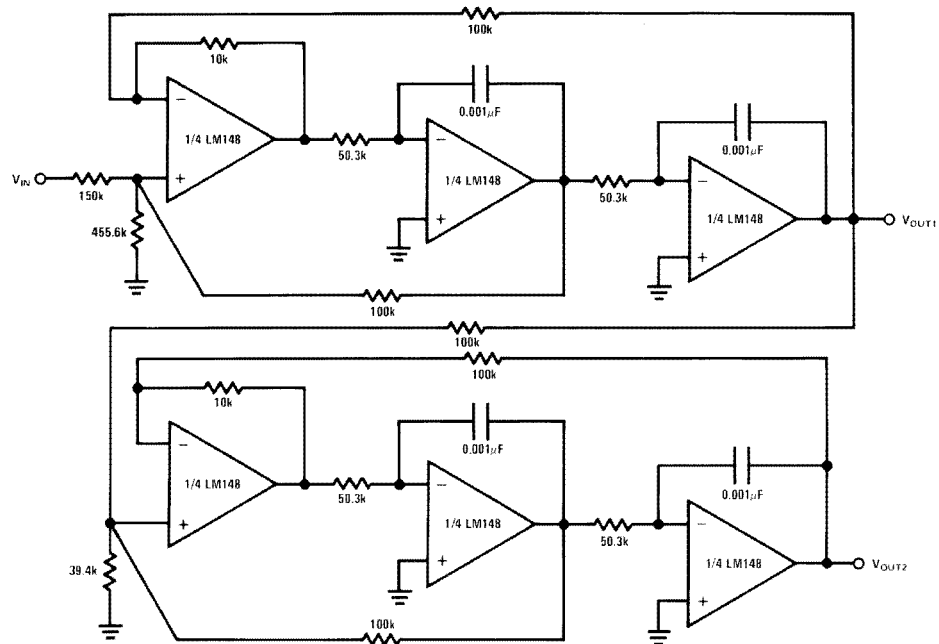


00778612

Use general equations, and tune each section separately

$Q_{1stSECTION} = 0.541$, $Q_{2ndSECTION} = 1.306$

The response should have 0 dB peaking

### A 3 Amplifier Bi-Quad Notch Filter



00778613

$$Q = \sqrt{\frac{R8}{R7}} \times \frac{R1C1}{\sqrt{R3C2R2C1}}, \quad f_o = \frac{1}{2\pi} \sqrt{\frac{R8}{R7}} \times \frac{1}{\sqrt{R2R3C1C2}}, \quad f_{NOTCH} = \frac{1}{2\pi} \sqrt{\frac{R6}{R3R5R7C1C2}}$$

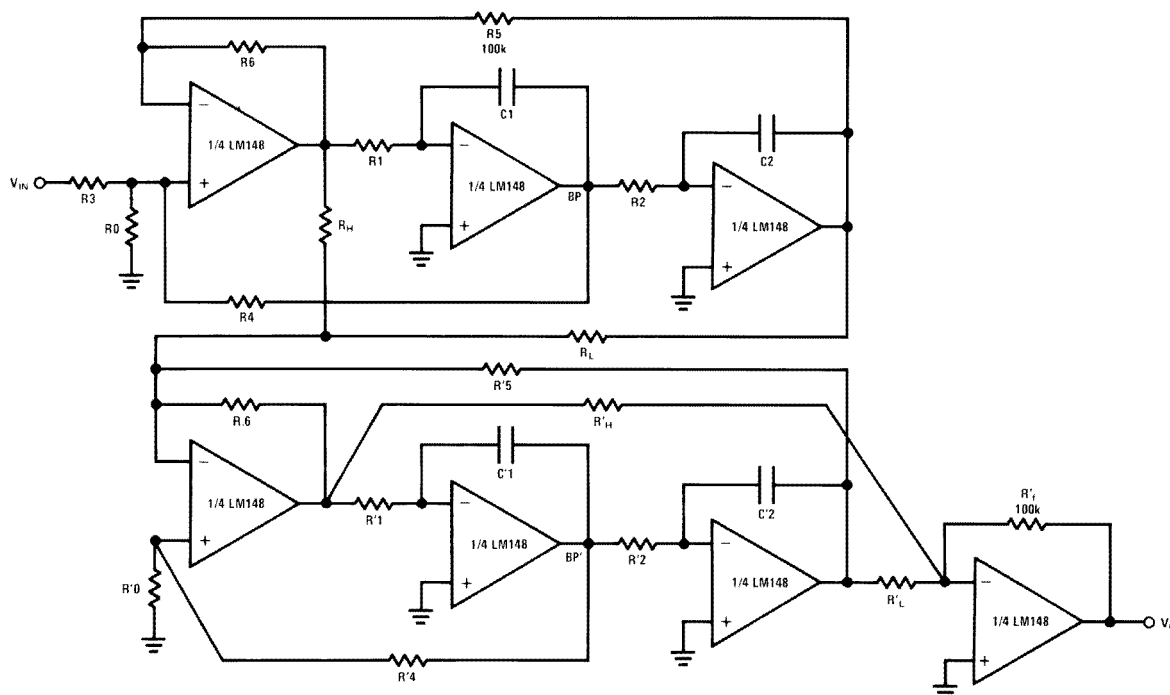Necessary condition for notch: $\frac{1}{R6} = \frac{R1}{R4R7}$

Ex: $f_{NOTCH}$ = 3 kHz, Q = 5, R1 = 270k, R2 = R3 = 20k, R4 = 27k, R5 = 20k, R6 = R8 = 10k, R7 = 100k, C1 = C2 = 0.001 µF

Better noise performance than the state-space approach.

## Typical Applications—LM148 (Continued)

### A 4th Order 1 kHz Elliptic Filter (4 Poles, 4 Zeros)



00778614

R1C1 = R2C2 = t

R'1C'1 = R'2C'2 = t'

$f_C$ = 1 kHz, $f_S$ = 2 kHz, $f_p$ = 0.543, $f_Z$ = 2.14, Q = 0.841, f'$_P$ = 0.987, f'$_Z$ = 4.92, Q' = 4.403, normalized to ripple BW

$$f = \frac{1}{2\pi R1C1} \times \sqrt{K}, \quad K = \frac{R4R5}{R3}\left(\frac{1}{r_{DS}} + \frac{1}{R4} + \frac{1}{R5}\right), \quad r_{DS} \approx \frac{R_{ON}}{\left(1 - \frac{V_{GS}}{V_P}\right)^{\frac{1}{2}}}$$

Use the BP outputs to tune Q, Q', tune the 2 sections separately

R1 = R2 = 92.6k, R3 = R4 = R5 = 100k, R6 = 10k, R0 = 107.8k, $R_L$ = 100k, $R_H$ = 155.1k,

R'1 = R'2 = 50.9k, R'4 = R'5 = 100k, R'6 = 10k, R'0 = 5.78k, R'$_L$ = 100k, R'$_H$ = 248.12k, R'f = 100k. All capacitors are 0.001 μF.

### Lowpass Response
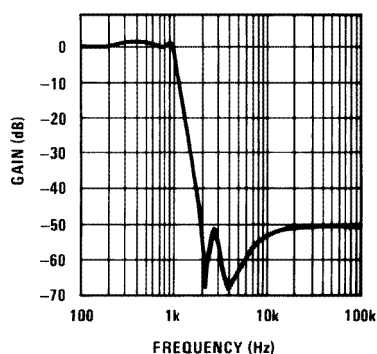


00778615

# Typical Simulation

**LM148, LM741 Macromodel for Computer Simulation**
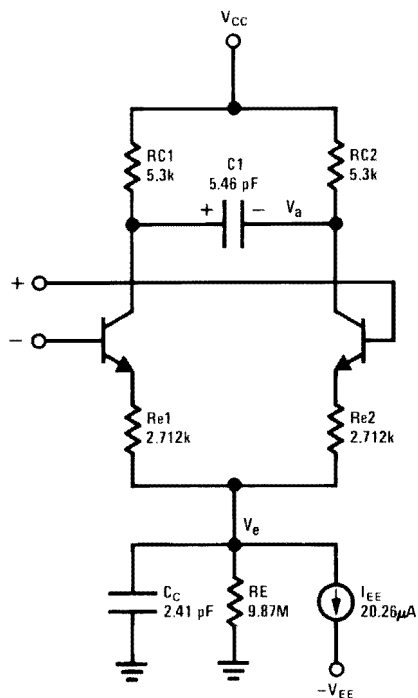


00778621

For more details, see IEEE Journal of Solid-State Circuits, Vol. SC-9, No. 6, December 1974

**Note 6:** $_{o1} = 112I_S = 8 \times 10^{-16}$

**Note 7:** $_{o2} = 144 \cdot C2 = 6$ pF for LM149



00778622

## Connection Diagram



00778602

**Top View**
**Order Number LM148J, LM148J/883, LM248J, LM348M, or LM348N**
**See NS Package Number J14A, M14A or N14A**
**LM148J is available per JM38510/11001**

## Physical Dimensions inches (millimeters)
unless otherwise noted

0.785
(19.939)
MAX

0.025
(0.635)
RAD

0.220−0.310
(5.588−7.874)

0.290−0.320
(7.366−8.128)

0.180
MAX
(4.572)

95° ±5°

10° MAX

0.310−0.410
(7.874−10.41)
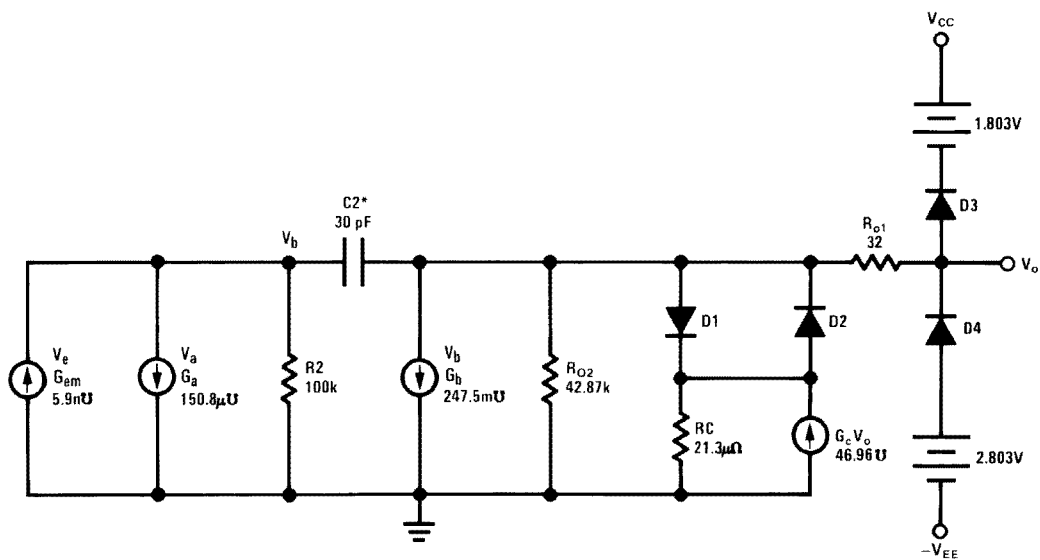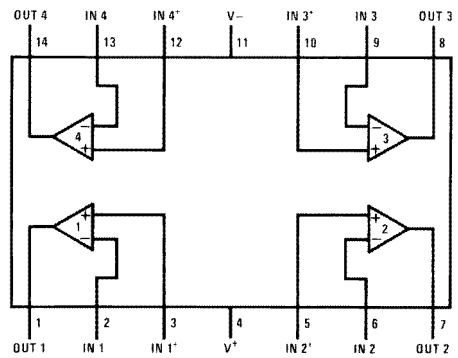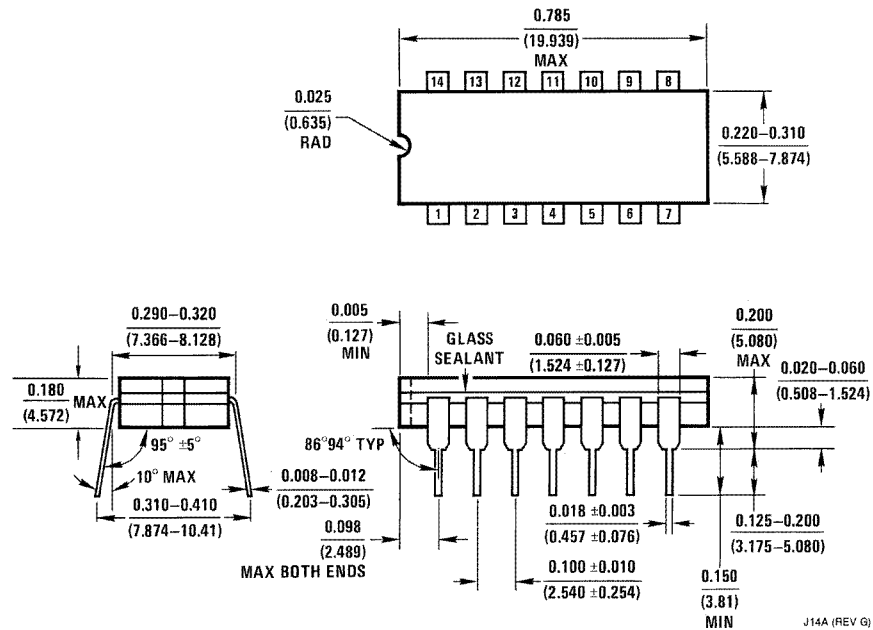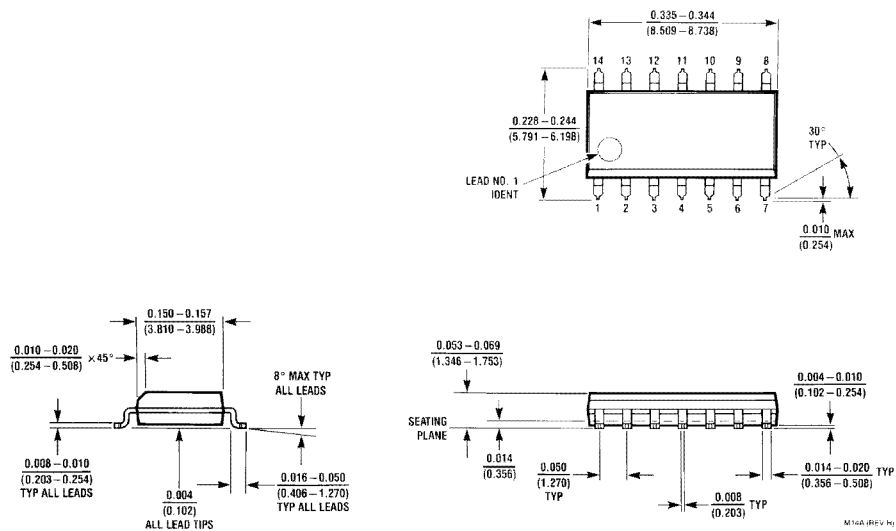
0.005
(0.127)
MIN

GLASS
SEALANT

86°94° TYP

0.008−0.012
(0.203−0.305)

0.098
(2.489)
MAX BOTH ENDS

0.060 ±0.005
(1.524 ±0.127)

0.018 ±0.003
(0.457 ±0.076)

0.100 ±0.010
(2.540 ±0.254)

0.200
(5.080)
MAX

0.020−0.060
(0.508−1.524)

0.125−0.200
(3.175−5.080)

0.150
(3.81)
MIN

J14A (REV G)

**Ceramic Dual-In-Line Package (J)**
**Order Number LM148J, LM148J/883, LM248J**
**NS Package Number J14A**

0.335−0.344
(8.509−8.738)

0.228−0.244
(5.791−6.198)

LEAD NO. 1
IDENT

30°
TYP

0.010 MAX
(0.254)

0.150−0.157
(3.810−3.988)

0.010−0.020
(0.254−0.508)
×45°

8° MAX TYP
ALL LEADS

0.008−0.010
(0.203−0.254)
TYP ALL LEADS

0.004
(0.102)
ALL LEAD TIPS

0.016−0.050
(0.406−1.270)
TYP ALL LEADS

0.053−0.069
(1.346−1.753)

0.004−0.010
(0.102−0.254)

SEATING
PLANE

0.014
(0.356)

0.050
(1.270)
TYP

0.008
(0.203) TYP

0.014−0.020
(0.356−0.508) TYP

M14A (REV H)

**S.O. Package (M)**
**Order Number LM348M or LM348MX**
**NS Package Number M14A**

# Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

0.740 − 0.770
(18.80 − 19.56)

0.090
(2.286)

0.250 ± 0.010
(6.350 ± 0.254)

PIN NO. 1 IDENT

0.092
(2.337) DIA

0.030 MAX DEPTH
(0.762)

OPTION 1

INDEX AREA

PIN NO. 1 IDENT

OPTION 02

0.135 ± 0.005
(3.429 ± 0.127)

0.145 − 0.200
(3.683 − 5.080)

0.060 TYP
(1.524)

4° TYP OPTIONAL

0.020
(0.508) MIN

0.125 − 0.150
(3.175 − 3.810)

0.014 − 0.023 TYP
(0.356 − 0.584)

90° ± 4° TYP

0.075 ± 0.015
(1.905 ± 0.381)

0.050 ± 0.010 TYP
(1.270 ± 0.254)

0.100 ± 0.010 TYP
(2.540 ± 0.254)

0.300 − 0.320
(7.620 − 8.128)

0.065
(1.651)

95° ± 5°

0.008 − 0.016 TYP
(0.203 − 0.406)

0.280
(7.112) MIN

0.325 $^{+0.040}_{-0.015}$
$\left(8.255 ^{+1.016}_{-0.381}\right)$

N14A (REV F)

**Molded Dual-In-Line Package (N)**
**Order Number LM348N**
**NS Package Number N14A**

## LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.

2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

## BANNED SUBSTANCE COMPLIANCE

National Semiconductor certifies that the products and packing materials meet the provisions of the Customer Products Stewardship Specification (CSP-9-111C2) and the Banned Substances and Materials of Interest Specification (CSP-9-111S2) and contain no "Banned Substances" as defined in CSP-9-111S2.