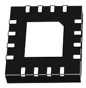
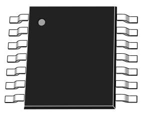
LM124, LM224x, LM324x

Datasheet

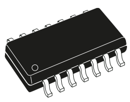
# Low-power quad operational amplifiers



QFN16 3x3



TSSOP14



SO14

## Features

- Wide gain bandwidth: 1.3 MHz
- Input common mode voltage range includes ground
- Large voltage gain: 100 dB
- Very low supply current/amplifier: 375 µA
- Low input bias current: 20 nA
- Low input voltage: 3 mV max.
- Low input offset current: 2 nA
- Wide power supply range:
  - Single supply: 3 V to 30 V
  - Dual supplies: ±1.5 V to ±15 V

## Related products

- See TSB572 and TSB611, 36 V newer technology devices, which have enhanced accuracy and ESD rating, reduced power consumption, and automotive grade qualification
- See LM2902 and LM2902W for automotive grade applications

## Description

The LM124, LM224x and LM324x consist of four independent, high gain operational amplifiers with frequency compensation implemented internally. They operate from a single power supply over a wide range of voltages.

Operation from split power supplies is also possible and the low-power supply current drain is independent of the magnitude of the power supply voltage.

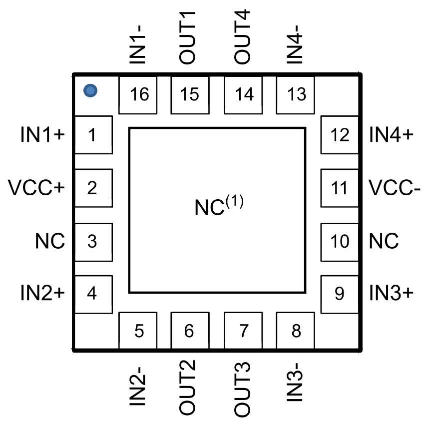
| Product status link |
|---|
| LM124, LM224x, LM324x |

| Product reference | Part numbers |
|---|---|
| LM124[1] | LM124 |
| LM224x | LM224, LM224A[2], LM224W[3] |
| LM324x | LM324, LM324A, LM324W[3] |

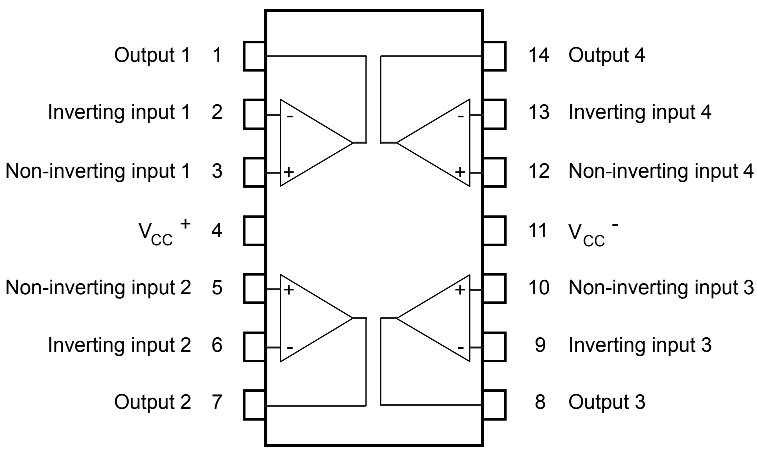
1. *Prefixes: LM1, LM2, and LM3 refer to temperature range*
2. *Suffix A refers to enhanced Vio performance*
3. *Suffix W refers to enhanced ESD ratings.*

# 1 Pin connections and schematic diagram

Figure 1. Pin connections (top view)




QFN16 3x3




TSSOP14/SO14

1. The exposed pads of the QFN16 3x3 can be connected to VCC- or left floating

Figure 2. Schematic diagram (LM224A, LM324A, LM224W, LM324W, one channel)

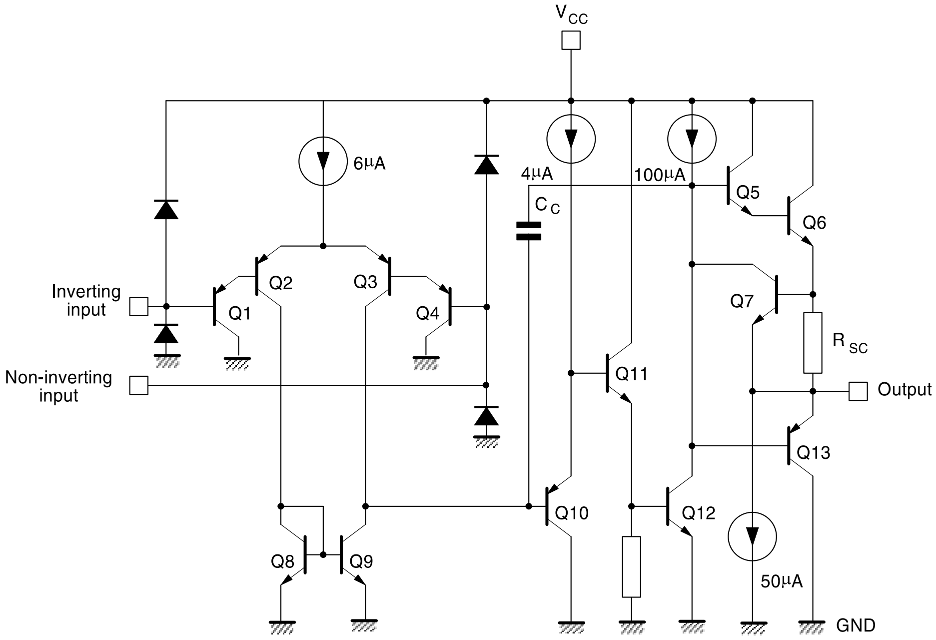
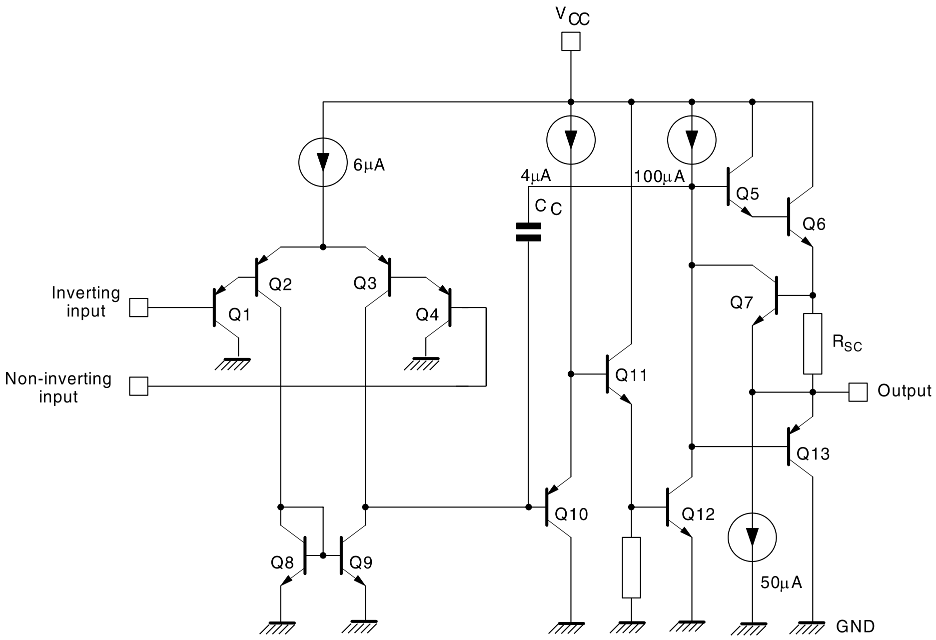



Figure 3. Schematic diagram (LM124, LM224, LM324, one channel)



# 2 Absolute maximum ratings and operating conditions

**Table 1. Absolute maximum ratings**

| Symbol | Parameter | | Value | Unit |
|---|---|---|---|---|
| $V_{CC}$ | Supply voltage | | ±16 or 32 | V |
| $V_i$ | Input voltage<br>LM224A, LM324A, LM224W, LM324W | | -0.3 to $V_{CC}$ + 0.3 | |
| | Input voltage<br>LM124, LM224, LM324 | | -0.3 to 32 | |
| $V_{id}$ | Differential input voltage [(1)] | | 32 | |
| $P_{tot}$ | Power dissipation: D suffix | | 400 | mW |
| | Output short-circuit duration [(2)] | | Infinite | |
| $I_{in}$ | Input current [(3)] | | 50 | mA |
| $T_{stg}$ | Storage temperature range | | -65 to 150 | °C |
| $T_j$ | Maximum junction temperature | | 150 | |
| $R_{thja}$ | Thermal resistance junction to ambient [(4)] | QFN16 3x3 | 45 | °C/W |
| | | TSSOP14 | 100 | |
| | | SO14 | 103 | |
| $R_{thjc}$ | Thermal resistance junction to case | QFN16 3x3 | 14 | |
| | | TSSOP14 | 32 | |
| | | SO14 | 31 | |
| ESD | HBM: human body model [(5)] | LM224A, LM324A | 800 | V |
| | | LM224W, LM324W | 700 | |
| | | LM124, LM224, LM324 | 250 | |
| | MM: machine model [(6)] | | 100 | |
| | CDM: charged device model | | 1500 | |

1. *Neither of the input voltages must exceed the magnitude of ($V_{CC}^{+}$) or ($V_{CC}^{-}$).*
2. *Short-circuits from the output to $V_{CC}$ can cause excessive heating if $V_{CC}$ > 15 V. The maximum output current is approximately 40 mA independent of the magnitude of $V_{CC}$. Destructive dissipation can result from simultaneous short-circuits on all amplifiers.*
3. *This input current only exists when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistor becoming forward biased and thereby acting as an input diode clamp. In addition to this diode action, there is also an NPN parasitic action on the IC chip. This transistor action can cause the output voltages of the op amps to go to the $V_{CC}$ voltage level (or to ground for a large overdrive) for the time during which an input is driven negative. This is not destructive and normal output starts up again for input voltages higher than -0.3 V.*
4. *Short-circuits can cause excessive heating. Destructive dissipation can result from simultaneous short-circuits on all amplifiers. These are typical values given for a single layer board (except for TSSOP which is a two-layer board).*
5. *Human body model: 100 pF discharged through a 1.5 kΩ resistor between two pins of the device, done for all couples of pin combinations with other pins floating.*
6. *Machine model: a 200 pF cap is charged to the specified voltage, then discharged directly between two pins of the device with no external series resistor (internal resistor < 5 Ω), done for all couples of pin combinations with other pins floating.*

Table 2. **Operating conditions**

| Symbol | Parameter | | Value | Unit |
|---|---|---|---|---|
| $V_{CC}$ | Supply voltage | Single supply | 3 to 30 | V |
| | | Dual supply | ±1.5 to ±15 | |
| $V_{ICM}$ | Common-mode input voltage range<br>Tamb= 25 °C | | 0 to $V_{CC}$ - 1.5 | |
| | Common-mode input voltage range<br>Tmin. ≤ Tamb ≤ Tmax. | | 0 to $V_{CC}$ -2 | |
| $T_{Oper}$ | Operating temperature range | LM124 | -55 to 125 | °C |
| | | LM224 | -40 to 105 | |
| | | LM324 | 0 to 70 | |

# 3 Electrical characteristics

**Table 3. $V_{CC+}$ = 5 V, $V_{CC-}$ = ground, $V_o$ = 1.4 V, $T_{amb}$ = 25 °C (unless otherwise specified)**

| Symbol | Parameter | | | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|---|
| $V_{io}$ LM224A, LM324A, LM224W, LM324W | Input offset voltage (1) | $T_{amb}$ = 25 °C | | | 2 | 3 | mV |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | | | 5 | |
| $V_{io}$ LM124, LM224, LM324 | | $T_{amb}$ = 25 °C | LM124 | | 2 | 5 | |
| | | | LM224 | | | | |
| | | | LM324 | | 2 | 7 | |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | LM124 | | | 7 | |
| | | | LM224 | | | | |
| | | | LM324 | | | 9 | |
| $I_{io}$ | Input offset current | $T_{amb}$ = 25 °C | | | 2 | 20 | nA |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | | | 40 | |
| $I_{ib}$ | Input bias current (2) | $T_{amb}$ = 25 °C | | | 20 | 100 | |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | | | 200 | |
| $A_{vd}$ | Large signal voltage gain, $V_{CC+}$= 15 V, $R_L$ = 2 kΩ, $V_o$ = 1.4 V to 11.4 V | $T_{amb}$ = 25 °C | | 50 | 100 | | V/mV |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | 25 | | | |
| SVR | Supply voltage rejection ratio, $R_s \leq$ 10 kΩ, $V_{CC+}$= 5 V to 30 V | $T_{amb}$ = 25 °C | | 65 | 110 | | dB |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | 65 | | | |
| $I_{CC}$ | Supply current, all amps, no load | $T_{amb}$ = 25 °C, $V_{CC}$ = 5V | | | 0.7 | 1.2 | mA |
| | | $T_{amb}$ = 25 °C, $V_{CC}$ = 30 V | | | 1.5 | 3 | |
| | | $T_{min} \leq T_{amb} \leq T_{max}$, $V_{CC}$ = 5 V | | | 0.8 | 1.2 | |
| | | $T_{min} \leq T_{amb} \leq T_{max}$, $V_{CC}$ = 30 V | | | 1.5 | 3 | |
| $V_{icm}$ | Input common mode voltage range (3) | $V_{CC}$ = 30 V, $T_{amb}$ = 25 °C | | 0 | | 28.5 | V |
| | | $V_{CC}$ = 30 V, $T_{min} \leq T_{amb} \leq T_{max}$ | | 0 | | 28 | |
| CMR | Common mode rejection ratio, $R_s \leq$ 10 kΩ | $T_{amb}$ = 25 °C | | 70 | 80 | | dB |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | 60 | | | |
| $I_{source}$ | Output current source, $V_{id}$ = 1 V | $V_{CC}$ = 15 V, $V_o$ = 2 V | | 20 | 40 | 70 | mA |
| $I_{sink}$ | Output sink current, $V_{id}$ = -1 V | $V_{CC}$ = 15 V, $V_o$ = 2 V | | 10 | 20 | | |
| | | $V_{CC}$ = 15 V, $V_o$ = 0.2 V | | 12 | 50 | | µA |

| Symbol | Parameter | | | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|---|
| $V_{OH}$ | High level output voltage, $V_{CC}$ = 30 V, $R_L$ = 2 kΩ | $T_{amb}$ = 25 °C | | 26 | 27 | | V |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | 26 | | | |
| | High level output voltage, $V_{CC}$ = 30 V, $R_L$ = 10 kΩ | $T_{amb}$ = 25 °C | | 27 | 28 | | |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | 27 | | | |
| | High level output voltage, $V_{CC}$ = 5 V, $R_L$ = 2 kΩ | $T_{amb}$ = 25 °C | | 3.5 | | | |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | 3 | | | |
| $V_{OL}$ | Low level output voltage, $R_L$ = 10 kΩ | $T_{amb}$ = 25 °C | | | 5 | 20 | mV |
| | | $T_{min} \leq T_{amb} \leq T_{max}$ | | | | 20 | |
| SR | Slew rate | $V_{CC}$ = 15 V, $V_i$ = 0.5 to 3 V, $R_L$ = 2 kΩ, $C_L$ = 100 pF, unity gain | | | 0.4 | | V/μs |
| GBP | Gain bandwidth product | $V_{CC}$ = 30 V, f = 100 kHz, $V_{in}$=10 mV, $R_L$ = 2 kΩ, $C_L$=100 pF | | | 1.3 | | MHz |
| THD | Total harmonic distortion | f = 1kHz, $A_v$ = 20 dB, $R_L$ = 2 kΩ, $V_o$ = 2 $V_{pp}$, $C_L$ = 100 pF, $V_{CC}$=30 V | | | 0.015 | | % |
| $e_n$ | Equivalent input noise voltage | f = 1 kHz, $R_s$ = 100 Ω, $V_{CC}$ = 30 V | | | 40 | | nV/√Hz |
| $DV_{io}$ | Input offset voltage drift | | | | 7 | 30 | μV/°C |
| $DI_{io}$ | Input offset current drift | | | | 10 | 200 | pA/°C |
| $V_{o1}/V_{o2}$ | Channel separation (4) | 1 kHz ≤ f ≤ 20 kHZ | | | 120 | | kHz |

1. *$V_o$ = 1.4 V, $R_s$ = 0 Ω, 5 V < $V_{CC}^+$ < 30 V, 0 < $V_{ic}$ < $V_{CC}^+$ - 1.5 V*
2. *The direction of the input current is out of the IC. This current is essentially constant, independent of the state of the output so there is no load change on the input lines.*
3. *The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3 V. The upper end of the common-mode voltage range is ($V_{CC}^+$) - 1.5 V, but either or both inputs can go to 32 V without damage.*
4. *Due to the proximity of external components, ensure that there is no coupling originating from stray capacitance between these external parts. Typically, this can be detected at higher frequencies because this type of capacitance increases.*

# 4 Electrical characteristic curves

**Figure 4.** Input bias current vs. temperature

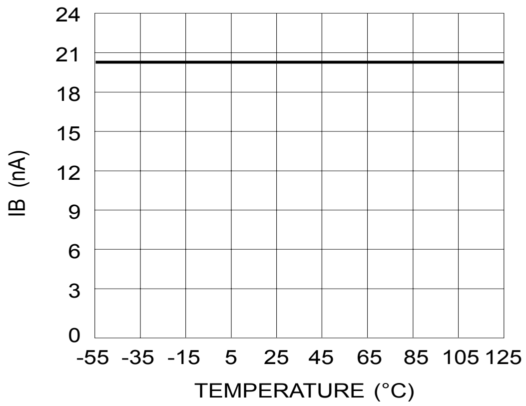



**Figure 5.** Output current limitation

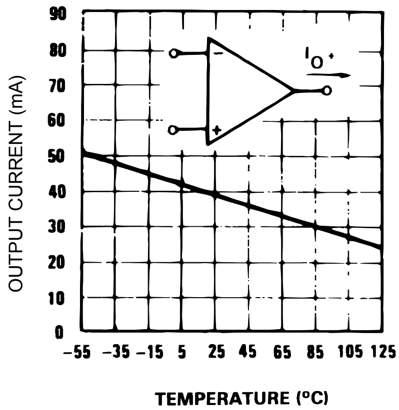



**Figure 6.** Input voltage range

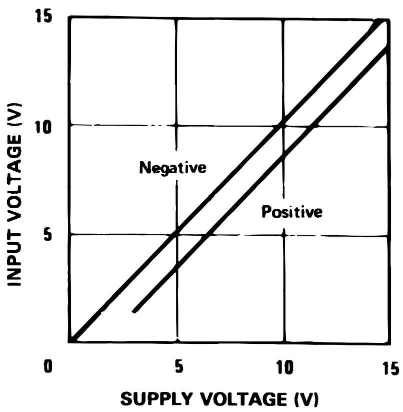



**Figure 7.** Supply current vs. supply voltage

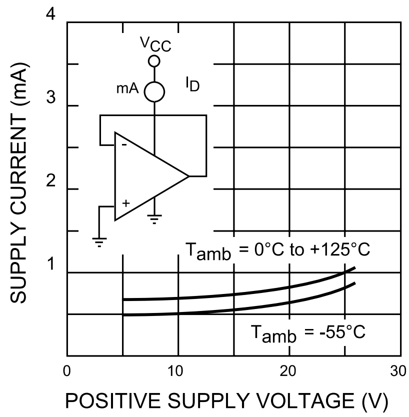



**Figure 8.** Gain bandwidth product vs. temperature

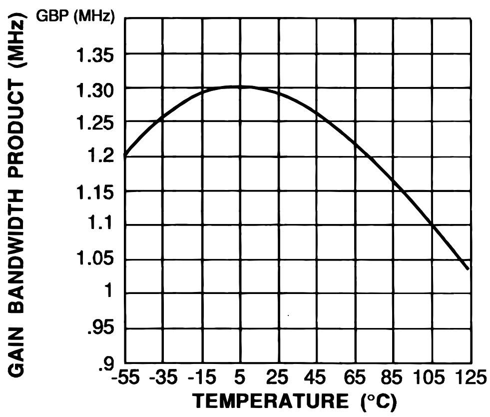



**Figure 9.** Common-mode rejection ratio

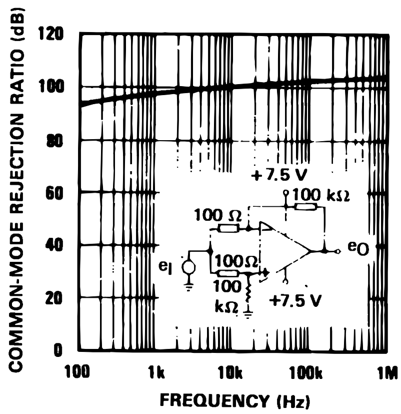


Figure 10. Open loop frequency response

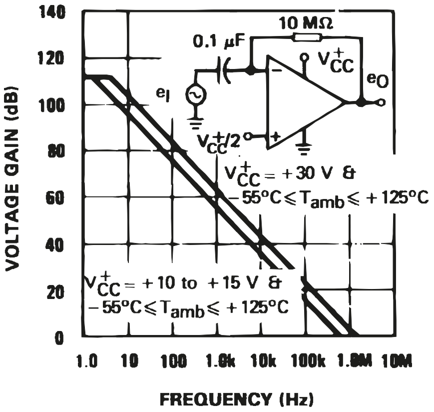



Figure 11. Large signal frequency response

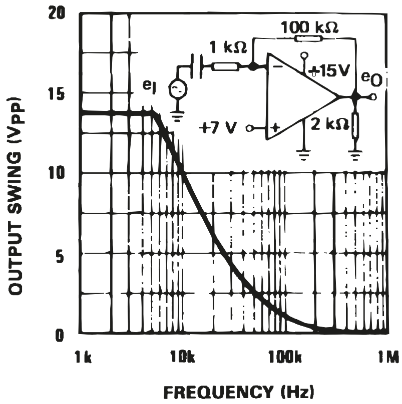



Figure 12. Voltage follower pulse response

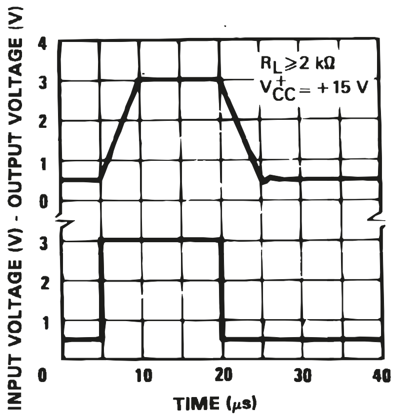



Figure 13. Output characteristics (current sinking)

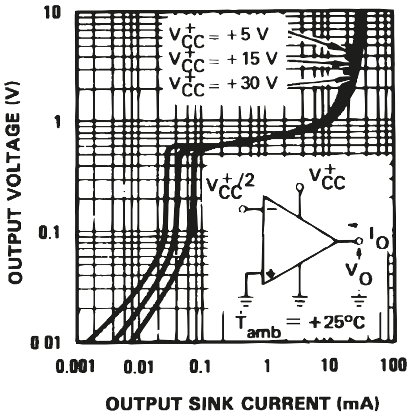



Figure 14. Voltage follower pulse response (small signal)

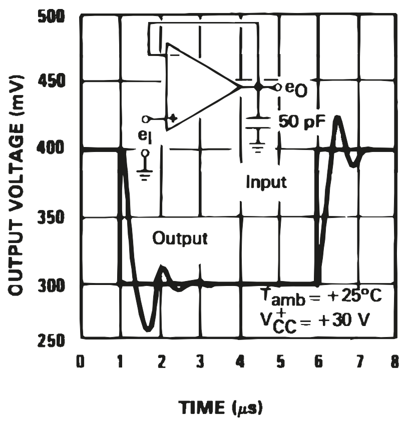



Figure 15. Output characteristics (current sourcing)

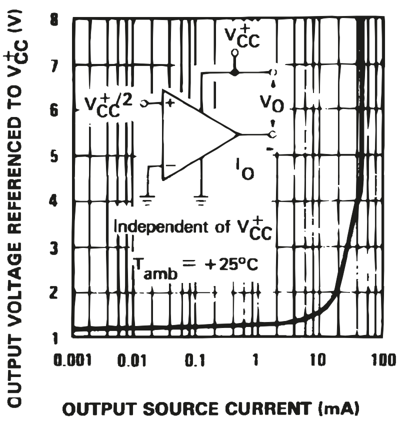


**Figure 16.** **Input current vs. supply voltage**

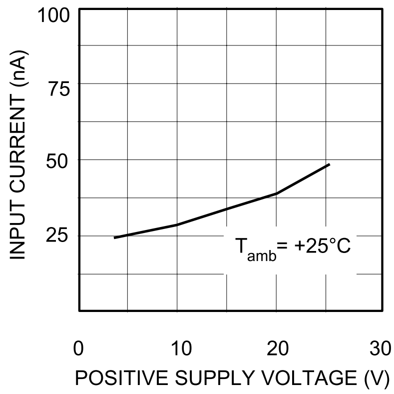



**Figure 17.** **Large signal voltage gain vs. temperature**

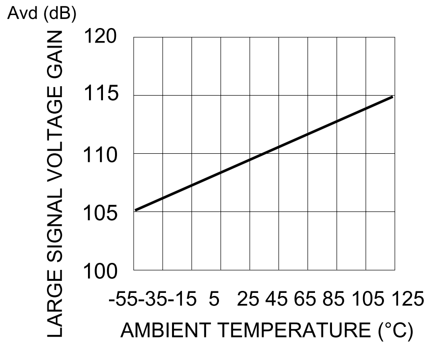



**Figure 18.** **Power supply and common mode rejection ratio vs. temperature**

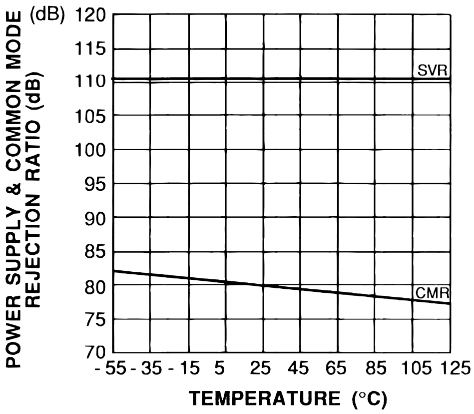
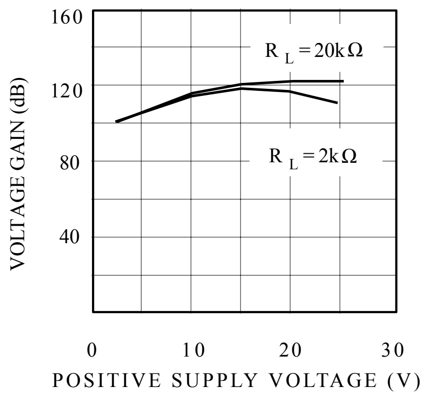



**Figure 19.** **Voltage gain vs. supply voltage**



# 5 Typical single-supply applications

Figure 20. AC coupled inverting amplifier

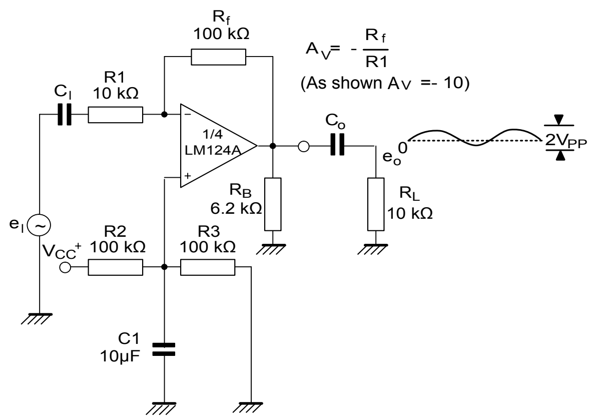



Figure 21. High input Z adjustable gain DC instrumentation amplifier

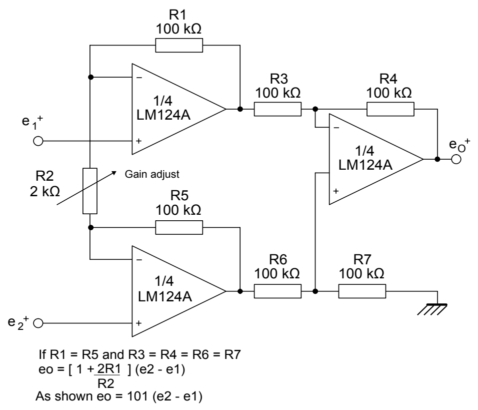



Figure 22. AC coupled non inverting amplifier

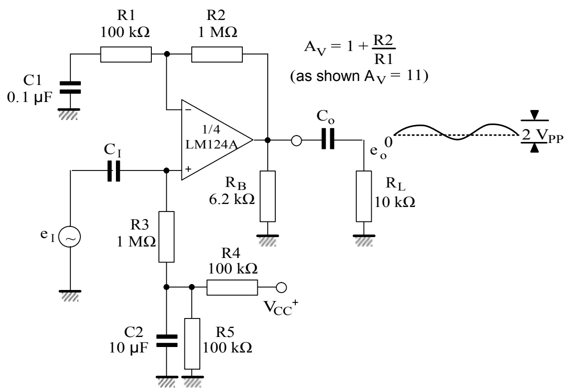



Figure 23. DC summing amplifier

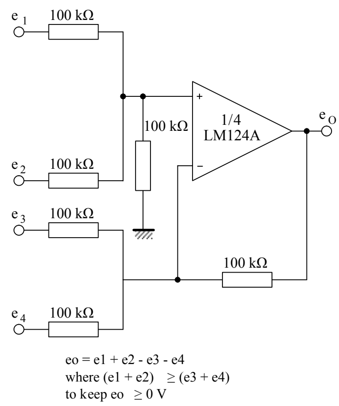



Figure 24. Non-inverting DC gain

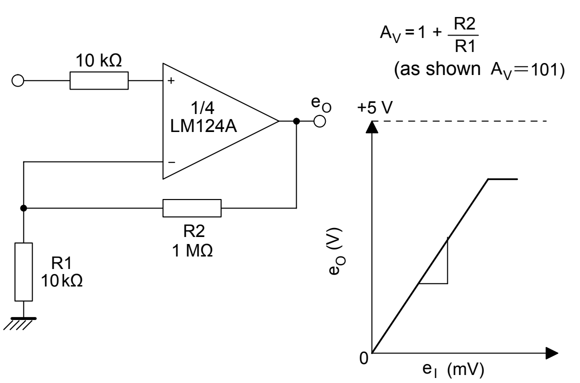



Figure 25. Low drift peak detector

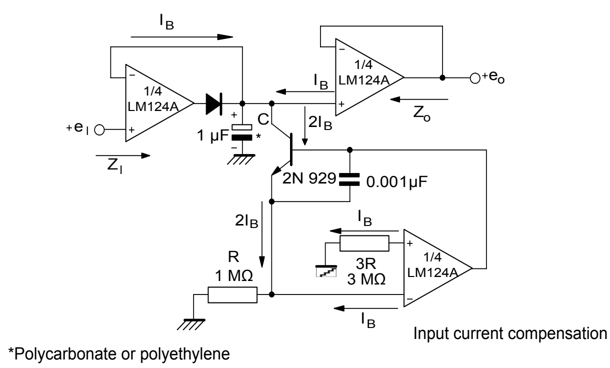


**Figure 26. Active bandpass filter**

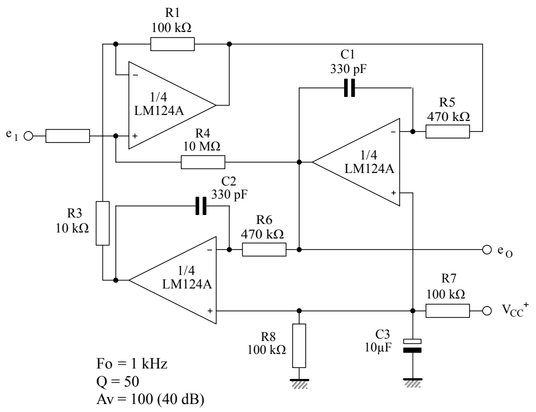
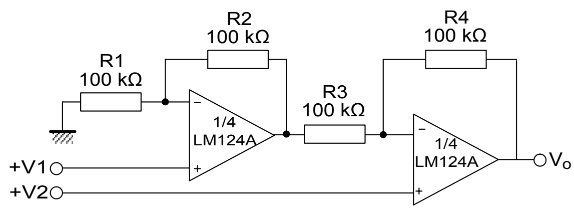



**Figure 27. High input Z, DC differential amplifier**

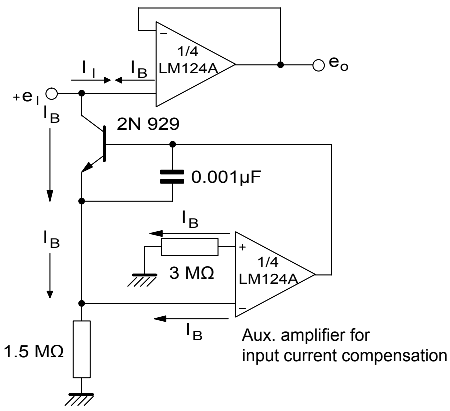
For $\frac{R_1}{R_2} = \frac{R_4}{R_3}$ CMRR depends on the following resistor ration match




$Vo = (1 + \frac{R4}{R3})\ (V2 - V1)$

As shown Vo = 2 * (V2 - V1)

**Figure 28. Using symmetrical amplifiers to reduce input current (general concept)**



# 6 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK packages, depending on their level of environmental compliance. ECOPACK specifications, grade definitions and product status are available at: www.st.com. ECOPACK is an ST trademark.

## 6.1 QFN16 3x3 package information

Figure 29. QFN16 3x3 package outline

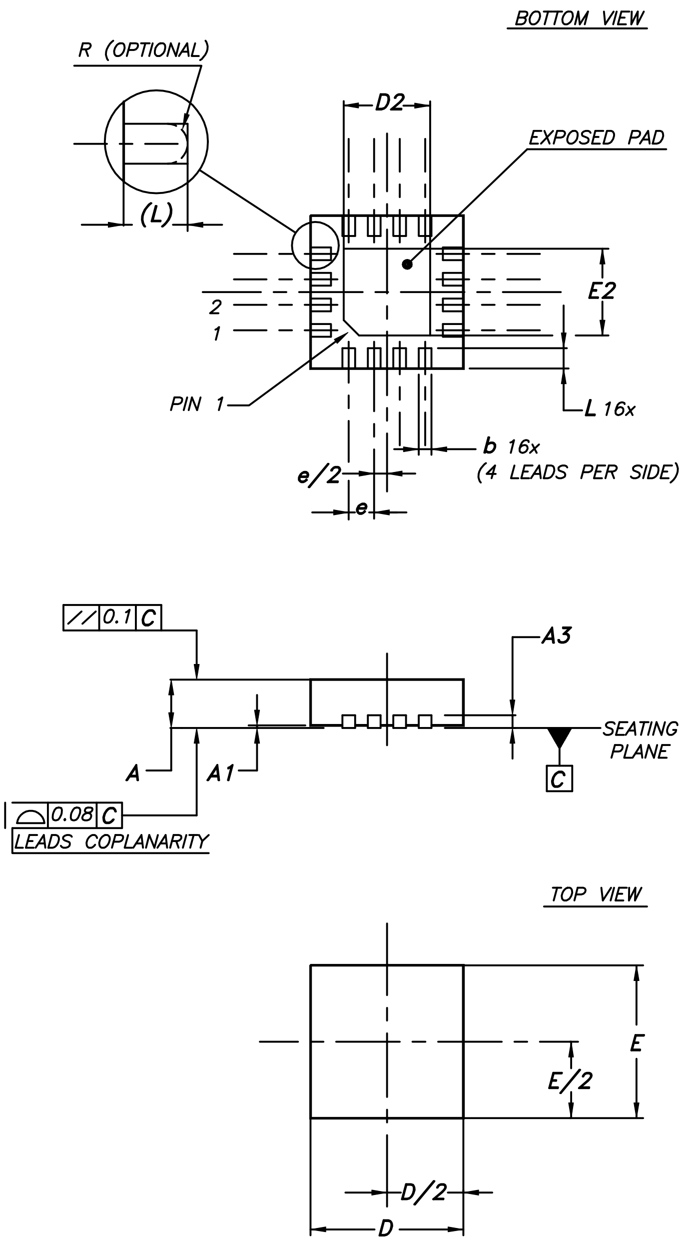
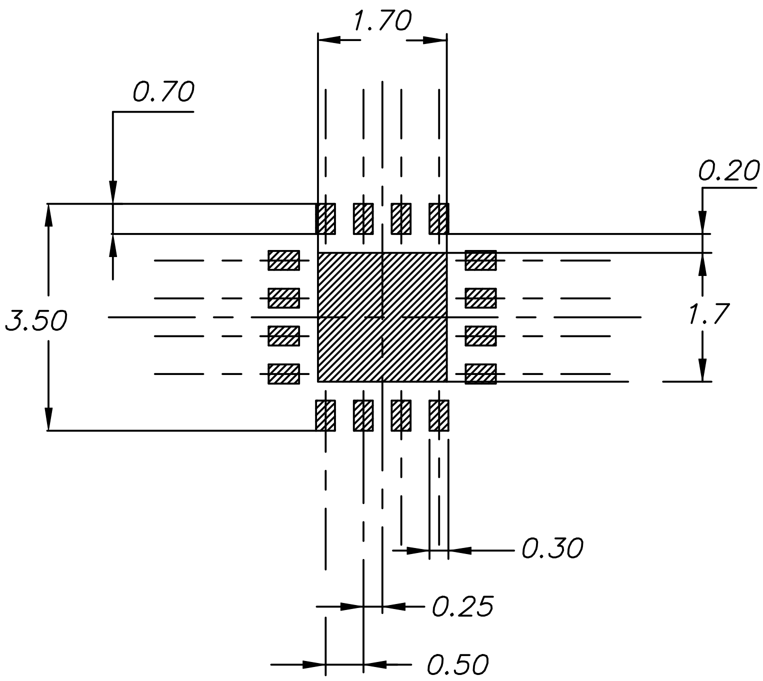


Table 4. QFN16 3x3 mechanical data

| Ref. | Dimensions | | | | | |
|---|---|---|---|---|---|---|
| | Millimeters | | | Inches | | |
| | Min. | Typ. | Max. | Min. | Typ. | Max. |
| A | 0.80 | 0.90 | 1.00 | 0.031 | 0.035 | 0.039 |
| A1 | 0 | | 0.05 | 0 | | 0.002 |
| A3 | | 0.20 | | | 0.008 | |
| b | 0.18 | | 0.30 | 0.007 | | 0.012 |
| D | 2.90 | 3.00 | 3.10 | 0.114 | 0.118 | 0.122 |
| D2 | 1.50 | | 1.80 | 0.059 | | 0.071 |
| E | 2.90 | 3.00 | 3.10 | 0.114 | 0.118 | 0.122 |
| E2 | 1.50 | | 1.80 | 0.059 | | 0.071 |
| e | | 0.50 | | | 0.020 | |
| L | 0.30 | | 0.50 | 0.012 | | 0.020 |

Figure 30. QFN16 3x3 recommended footprint



## 6.2 TSSOP14 package information

Figure 31. TSSOP14 package outline

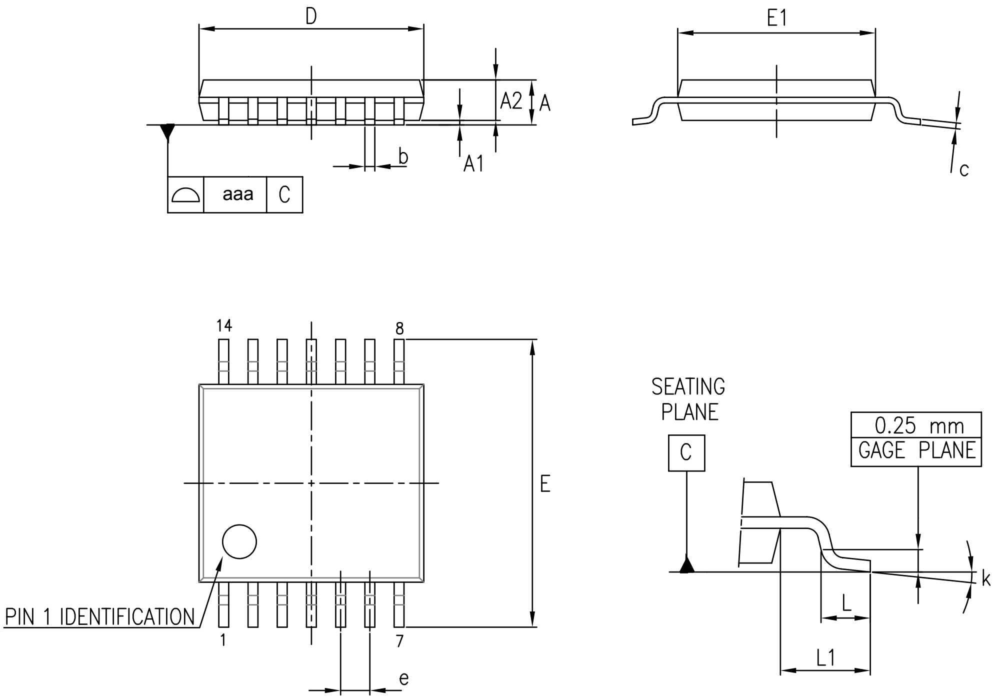



Table 5. TSSOP14 package mechanical data

| Ref. | Dimensions | | | | | |
|---|---|---|---|---|---|---|
| | Millimeters | | | Inches | | |
| | Min. | Typ. | Max. | Min. | Typ. | Max. |
| A | | | 1.20 | | | 0.047 |
| A1 | 0.05 | | 0.15 | 0.002 | 0.004 | 0.006 |
| A2 | 0.80 | 1.00 | 1.05 | 0.031 | 0.039 | 0.041 |
| b | 0.19 | | 0.30 | 0.007 | | 0.012 |
| c | 0.09 | | 0.20 | 0.004 | | 0.0089 |
| D | 4.90 | 5.00 | 5.10 | 0.193 | 0.197 | 0.201 |
| E | 6.20 | 6.40 | 6.60 | 0.244 | 0.252 | 0.260 |
| E1 | 4.30 | 4.40 | 4.50 | 0.169 | 0.173 | 0.176 |
| e | | 0.65 | | | 0.0256 | |
| L | 0.45 | 0.60 | 0.75 | 0.018 | 0.024 | 0.030 |
| L1 | | 1.00 | | | 0.039 | |
| k | 0° | | 8° | 0° | | 8° |
| aaa | | | 0.10 | | | 0.004 |

## 6.3 SO14 package information

Figure 32. SO14 package outline

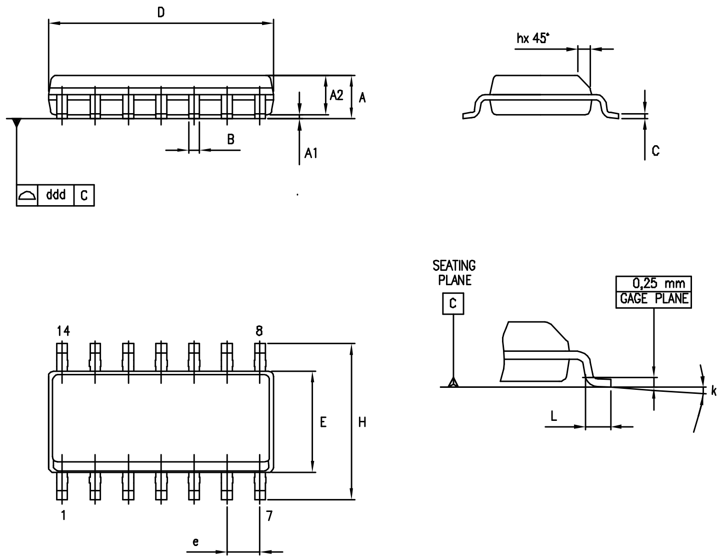



Table 6. SO14 package mechanical data

| Ref. | Dimensions | | | | | |
|---|---|---|---|---|---|---|
| | Millimeters | | | Inches | | |
| | Min. | Typ. | Max. | Min. | Typ. | Max. |
| | | | 1.75 | | | 0.069 |
| A | 1.35 | | 1.75 | 0.05 | | 0.068 |
| A1 | 0.10 | | 0.25 | 0.004 | | 0.009 |
| A2 | 1.10 | | 1.65 | 0.04 | | 0.06 |
| B | 0.33 | | 0.51 | 0.01 | | 0.02 |
| C | 0.19 | | 0.25 | 0.007 | | 0.009 |
| D | 8.55 | | 8.75 | 0.33 | | 0.34 |
| E | 3.80 | | 4.0 | 0.15 | | 0.15 |
| e | | 1.27 | | | 0.05 | |
| H | 5.80 | | 6.20 | 0.22 | | 0.24 |
| h | 0.25 | | 0.50 | 0.009 | | 0.02 |
| L | 0.40 | | 1.27 | 0.015 | | 0.05 |
| k | 8° (max.) | | | | | |
| ddd | | | 0.10 | | | 0.004 |

# 7 Ordering information

**Table 7.** Order codes

<table>
<tr><th>Order code</th><th>Temperature range</th><th>ESD (HBM, CDM)</th><th>$V_{io}$ max. @ 25 °C</th><th>Package</th><th>Marking</th></tr>
<tr><td>LM124DT</td><td>-55 °C to 125 °C</td><td>250 V, 1.5 kV</td><td>5 mV</td><td rowspan="2">SO14</td><td>124</td></tr>
<tr><td>LM224ADT</td><td rowspan="6">-40 °C to 105 °C</td><td rowspan="2">800 V, 1.5 kV</td><td rowspan="2">3 mV</td><td rowspan="2">224A</td></tr>
<tr><td>LM224APT</td><td>TSSOP14</td></tr>
<tr><td>LM224DT</td><td rowspan="3">250 V, 1.5 kV</td><td rowspan="3">5 mV</td><td>SO14</td><td rowspan="2">224</td></tr>
<tr><td>LM224PT</td><td>TSSOP14</td></tr>
<tr><td>LM224QT</td><td>QFN16 3x3</td><td>K425</td></tr>
<tr><td>LM224WDT</td><td>700 V, 1.5 kV</td><td rowspan="7">3 mV</td><td rowspan="2">SO14</td><td>224W</td></tr>
<tr><td>LM324ADT</td><td rowspan="9">0 °C to 70 °C</td><td rowspan="2">800 V, 1.5 kV</td><td rowspan="2">324A</td></tr>
<tr><td>LM324APT</td><td>TSSOP14</td></tr>
<tr><td>LM324AWDT</td><td rowspan="4">700 V, 1.5 kV</td><td>SO14</td><td rowspan="2">324AW</td></tr>
<tr><td>LM324AWPT</td><td>TSSOP14</td></tr>
<tr><td>LM324WDT</td><td>SO14</td><td rowspan="2">324W</td></tr>
<tr><td>LM324WPT</td><td>TSSOP14</td></tr>
<tr><td>LM324DT</td><td rowspan="3">250 V, 1.5 kV</td><td rowspan="3">5 mV</td><td>SO14</td><td rowspan="2">324</td></tr>
<tr><td>LM324PT</td><td>TSSOP14</td></tr>
<tr><td>LM324QT</td><td>QFN16 3x3</td><td>K427</td></tr>
</table>

## Revision history

Table 8. **Document revision history**

| Date | Revision | Changes |
|---|---|---|
| 1-Mar-2001 | 1 | First release |
| 1-Feb-2005 | 2 | Added explanation of $V_{id}$ and $V_i$ limits in Table 2 on page 4.<br>Updated macromodel. |
| 1-Jun-2005 | 3 | ESD protection inserted in Table 2 on page 4. |
| 25-Sep-2006 | 4 | Editorial update. |
| 22-Aug-2013 | 5 | Removed DIP package and all information pertaining to it<br>Table 1: Device summary: Removed order codes LM224AN, LM224AD, LM324AN, and LM324AD; updated packaging.<br>Table 2: Absolute maximum ratings: removed N suffix power dissipation data; updated footnotes 5 and 6.<br>Renamed Figure 3, Figure 4, Figure 6, Figure 7, Figure 16, Figure 17, Figure 18, and Figure 19.<br>Updated axes titles of Figure 4, Figure 5, Figure 7, and Figure 17.<br>Removed duplicate figures.<br>Removed Section 5: Macromodels |
| 06-Dec-2013 | 6 | Table 2: Absolute maximum ratings: updated ESD data for HBM and MM. |
| 10-Jun-2016 | 7 | LM124, LM224, LM324 and LM224W, LM324W datasheets merged with LM224A, LM324A datasheet. The following sections were reworked: Features, Description, Section 1: "Pin connections and schematic diagram", Section 2: "Absolute maximum ratings and operating conditions", and Section 3: "Electrical characteristics". The following sections were added: Related products and Section 7: "Ordering information". Packaged silhouettes, pin connections, and mechanical data were standardized and updated. |
| 09-Sep-2019 | 8 | Updated cover page, Section 2 Absolute maximum ratings and operating conditions and Table 3. $V_{CC+}$ = 5 V, $V_{CC-}$ = ground, $V_o$ = 1.4 V, $T_{amb}$ = 25 °C (unless otherwise specified). Updated Figure 2. Schematic diagram (LM224A, LM324A, LM224W, LM324W, one channel) and Figure 3. Schematic diagram (LM124, LM224, LM324, one channel). |

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