

# LM124, LM124A, LM224, LM224A LM324, LM324A, LM2902 QUADRUPLE OPERATIONAL AMPLIFIERS

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- **Wide Range of Supply Voltages:**  
Single Supply . . . 3 V to 30 V  
(LM2902, 3 V to 26 V) or Dual Supplies
- **Low Supply-Current Drain Independent of Supply Voltage . . . 0.8 mA Typ**
- **Common-Mode Input Voltage Range Includes Ground, Allowing Direct Sensing Near Ground**
- **Low Input Bias and Offset Parameters:**
  - Input Offset Voltage . . . 3 mV Typ  
A Versions . . . 2 mV Typ
  - Input Offset Current . . . 2 nA Typ
  - Input Bias Current . . . 20 nA Typ  
A Versions . . . 15 nA Typ
- **Differential Input Voltage Range Equal to Maximum-Rated Supply Voltage . . . 32 V (26 V for LM2902)**
- **Open-Loop Differential Voltage Amplification . . . 100 V/mV Typ**
- **Internal Frequency Compensation**

## description/ordering information

These devices consist of four independent high-gain frequency-compensated operational amplifiers that are designed specifically to operate from a single supply over a wide range of voltages. Operation from split supplies also is possible when the difference between the two supplies is 3 V to 30 V (for the LM2902, 3 V to 26 V) and  $V_{CC}$  is at least 1.5 V more positive than the input common-mode voltage. The low supply-current drain is independent of the magnitude of the supply voltage.

Applications include transducer amplifiers, dc amplification blocks, and all the conventional operational-amplifier circuits that now can be more easily implemented in single-supply-voltage systems. For example, the LM124 can be operated directly from the standard 5-V supply that is used in digital systems and easily provides the required interface electronics without requiring additional  $\pm 15$ -V supplies.

LM124 . . . D, J, OR W PACKAGE

LM124A . . . J PACKAGE

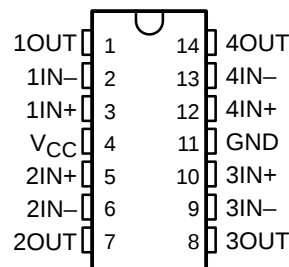
LM224, LM224A . . . D OR N PACKAGE

LM324 . . . D, N, NS, OR PW PACKAGE

LM324A . . . D, DB, N, NS, OR PW PACKAGE

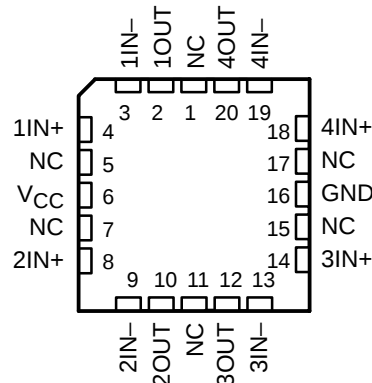
LM2902 . . . D, N, NS, OR PW PACKAGE

(TOP VIEW)



LM124, LM124A . . . FK PACKAGE

(TOP VIEW)



NC – No internal connection

LM124, LM124A, LM224, LM224A  
 LM324, LM324A, LM2902  
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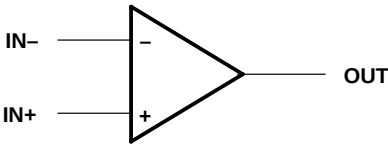
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ORDERING INFORMATION

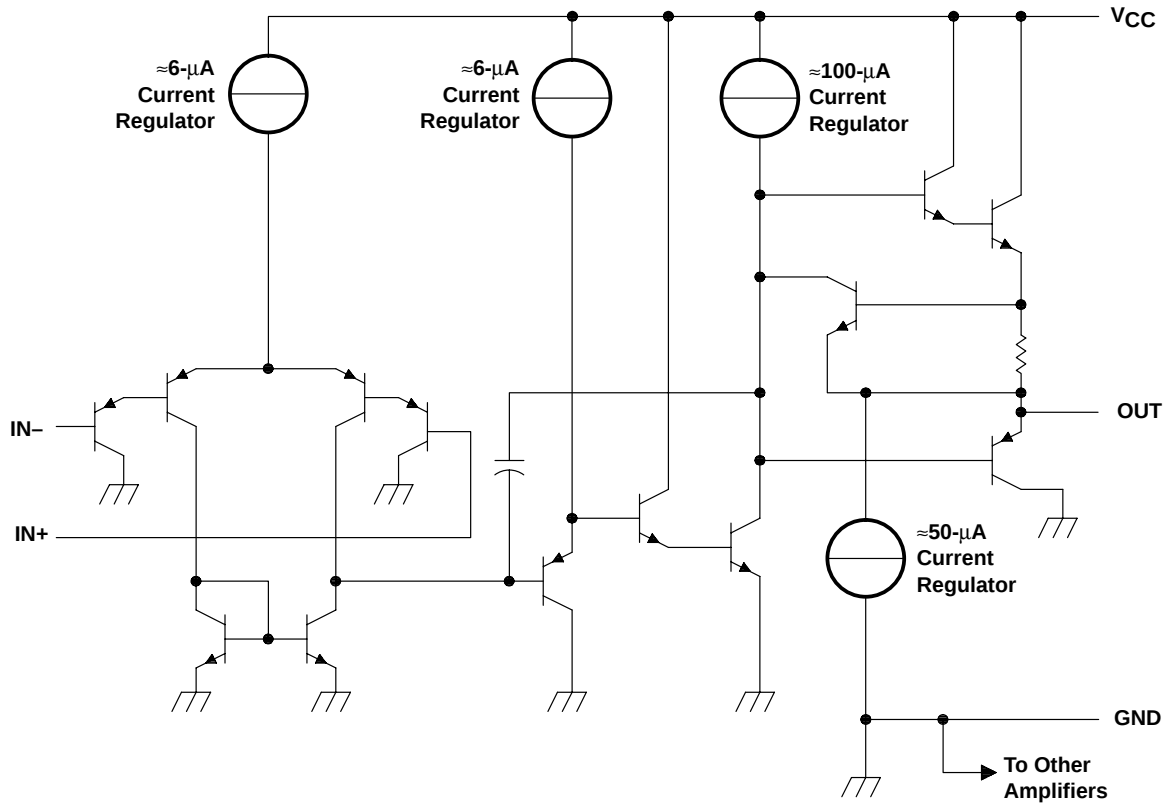
| T <sub>A</sub> | V <sub>IO</sub> max<br>AT 25°C | PACKAGE†   |               | ORDERABLE<br>PART NUMBER | TOP-SIDE<br>MARKING |
|----------------|--------------------------------|------------|---------------|--------------------------|---------------------|
| 0°C to 70°C    | 7 mV                           | PDIP (N)   | Tube          | LM324N                   | LM324N              |
|                |                                | SOIC (D)   | Tube          | LM324D                   | LM324               |
|                |                                |            | Tape and reel | LM324DR                  |                     |
|                |                                | SOP (NS)   | Tape and reel | LM324NSR                 | LM324               |
|                |                                | TSSOP (PW) | Tape and reel | LM324PWR                 | L324                |
|                | 3 mV                           | PDIP (N)   | Tube          | LM324AN                  | LM324AN             |
|                |                                | SOIC (D)   | Tube          | LM324AD                  | LM324A              |
|                |                                |            | Tape and reel | LM324ADR                 |                     |
|                |                                | SOP (NS)   | Tape and reel | LM324ANSR                | LM324A              |
|                |                                | SSOP (DB)  | Tape and reel | LM324ADBR                | LM324A              |
|                |                                | TSSOP (PW) | Tape and reel | LM324APWR                | L324A               |
| –25°C to 85°C  | 5 mV                           | PDIP (N)   | Tube          | LM224N                   | LM224N              |
|                |                                | SOIC (D)   | Tube          | LM224D                   | LM224               |
|                |                                |            | Tape and reel | LM224DR                  |                     |
|                | 3 mV                           | PDIP (N)   | Tube          | LM224AN                  | LM224AN             |
|                |                                | SOIC (D)   | Tube          | LM224AD                  | LM224A              |
|                |                                |            | Tape and reel | LM224ADR                 |                     |
| –40°C to 125°C | 7 mV                           | PDIP (N)   | Tube          | LM2902N                  | LM2902N             |
|                |                                | SOIC (D)   | Tube          | LM2902D                  | LM2902              |
|                |                                |            | Tape and reel | LM2902DR                 |                     |
|                |                                | SOP (NS)   | Tape and reel | LM2902NSR                | LM2902              |
|                |                                | TSSOP (PW) | Tape and reel | LM2902PWR                | L2902               |
| –55°C to 125°C | 5 mV                           | CDIP (J)   | Tube          | LM124J                   | LM124J              |
|                |                                | CFP (W)    | Tube          | LM124JB                  | LM124JB             |
|                |                                |            | Tube          | LM124W                   |                     |
|                |                                | LCCC (FK)  | Tube          | LM124FKB                 | LM124FKB            |
|                |                                | SOIC (D)   | Tube          | LM124D                   | LM124               |
|                |                                |            | Tape and reel | LM124DR                  |                     |
|                | 2 mV                           | CDIP (J)   | Tube          | LM124AJ                  | LM124AJ             |
|                |                                |            | Tube          | LM124AJB                 | LM124AJB            |
|                |                                | LCCC (FK)  | Tube          | LM124AFKB                | LM124AFKB           |

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at [www.ti.com/sc/package](http://www.ti.com/sc/package).

symbol (each amplifier)



schematic (each amplifier)



| COMPONENT COUNT<br>(total device) |    |
|-----------------------------------|----|
| Epi-FET                           | 1  |
| Transistors                       | 95 |
| Diodes                            | 4  |
| Resistors                         | 11 |
| Capacitors                        | 4  |

**LM124, LM124A, LM224, LM224A  
LM324, LM324A, LM2902  
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**absolute maximum ratings over operating free-air temperature range (unless otherwise noted)<sup>†</sup>**

|                                                                                                                                               |                | LM124, LM124A<br>LM224, LM224A<br>LM324, LM324A | LM2902     | UNIT               |
|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------|-------------------------------------------------|------------|--------------------|
| Supply voltage, $V_{CC}$ (see Note 1)                                                                                                         |                | 32                                              | 26         | V                  |
| Differential input voltage, $V_{ID}$ (see Note 2)                                                                                             |                | $\pm 32$                                        | $\pm 26$   | V                  |
| Input voltage, $V_I$ (either input)                                                                                                           |                | -0.3 to 32                                      | -0.3 to 26 | V                  |
| Duration of output short circuit (one amplifier) to ground at (or below) $T_A = 25^\circ\text{C}$ ,<br>$V_{CC} \leq 15\text{ V}$ (see Note 3) |                | Unlimited                                       | Unlimited  |                    |
| Operating virtual junction temperature, $T_J$                                                                                                 |                | 150                                             | 150        | $^\circ\text{C}$   |
| Package thermal impedance, $\theta_{JA}$ (see Notes 4 and 5)                                                                                  | D package      | 86                                              | 86         | $^\circ\text{C/W}$ |
|                                                                                                                                               | DB package     | 96                                              |            |                    |
|                                                                                                                                               | N package      | 80                                              | 80         |                    |
|                                                                                                                                               | NS package     | 76                                              | 76         |                    |
|                                                                                                                                               | PW package     | 113                                             | 113        |                    |
| Package thermal impedance, $\theta_{JC}$ (see Notes 6 and 7)                                                                                  | FK package     | 5.61                                            |            | $^\circ\text{C/W}$ |
|                                                                                                                                               | J package      | 15.05                                           |            |                    |
|                                                                                                                                               | W package      | 14.65                                           |            |                    |
| Case temperature for 60 seconds                                                                                                               | FK package     | 260                                             |            | $^\circ\text{C}$   |
| Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds                                                                                  | J or W package | 300                                             | 300        | $^\circ\text{C}$   |
| Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds                                                                                  | N package      | 260                                             | 260        | $^\circ\text{C}$   |
| Storage temperature range, $T_{stg}$                                                                                                          |                | -65 to 150                                      | -65 to 150 | $^\circ\text{C}$   |

<sup>†</sup> 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.

- NOTES:
1. All voltage values (except differential voltages and  $V_{CC}$  specified for the measurement of  $I_{OS}$ ) are with respect to the network GND.
  2. Differential voltages are at  $IN+$  with respect to  $IN-$ .
  3. Short circuits from outputs to  $V_{CC}$  can cause excessive heating and eventual destruction.
  4. Maximum power dissipation is a function of  $T_J(\text{max})$ ,  $\theta_{JA}$ , and  $T_A$ . The maximum allowable power dissipation at any allowable ambient temperature is  $P_D = (T_J(\text{max}) - T_A)/\theta_{JA}$ . Operating at the absolute maximum  $T_J$  of  $150^\circ\text{C}$  can affect reliability.
  5. The package thermal impedance is calculated in accordance with JESD 51-7.
  6. Maximum power dissipation is a function of  $T_J(\text{max})$ ,  $\theta_{JC}$ , and  $T_C$ . The maximum allowable power dissipation at any allowable case temperature is  $P_D = (T_J(\text{max}) - T_C)/\theta_{JC}$ . Operating at the absolute maximum  $T_J$  of  $150^\circ\text{C}$  can affect reliability.
  7. The package thermal impedance is calculated in accordance with MIL-STD-883.

electrical characteristics at specified free-air temperature,  $V_{CC} = 5\text{ V}$  (unless otherwise noted)

| PARAMETER                        |                                                                      | TEST CONDITIONS†                                                                                | T <sub>A</sub> ‡ | LM124, LM224              |      |      | LM324                     |      |      | LM2902                    |      |      | UNIT |
|----------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|------------------|---------------------------|------|------|---------------------------|------|------|---------------------------|------|------|------|
|                                  |                                                                      |                                                                                                 |                  | MIN                       | TYP§ | MAX  | MIN                       | TYP§ | MAX  | MIN                       | TYP§ | MAX  |      |
| V <sub>IO</sub>                  | Input offset voltage                                                 | V <sub>CC</sub> = 5 V to MAX,<br>V <sub>IC</sub> = V <sub>ICRmin</sub> , V <sub>O</sub> = 1.4 V | 25°C             |                           | 3    | 5    |                           | 3    | 7    |                           | 3    | 7    | mV   |
|                                  |                                                                      |                                                                                                 | Full range       |                           |      | 7    |                           |      | 9    |                           |      | 10   |      |
| I <sub>IO</sub>                  | Input offset current                                                 | V <sub>O</sub> = 1.4 V                                                                          | 25°C             |                           | 2    | 30   |                           | 2    | 50   |                           | 2    | 50   | nA   |
|                                  |                                                                      |                                                                                                 | Full range       |                           |      | 100  |                           |      | 150  |                           |      | 300  |      |
| I <sub>IB</sub>                  | Input bias current                                                   | V <sub>O</sub> = 1.4 V                                                                          | 25°C             |                           | –20  | –150 |                           | –20  | –250 |                           | –20  | –250 | nA   |
|                                  |                                                                      |                                                                                                 | Full range       |                           |      | –300 |                           |      | –500 |                           |      | –500 |      |
| V <sub>ICR</sub>                 | Common-mode input voltage range                                      | V <sub>CC</sub> = 5 V to MAX                                                                    | 25°C             | 0 to V <sub>CC</sub> –1.5 |      |      | 0 to V <sub>CC</sub> –1.5 |      |      | 0 to V <sub>CC</sub> –1.5 |      |      | V    |
|                                  |                                                                      |                                                                                                 | Full range       | 0 to V <sub>CC</sub> –2   |      |      | 0 to V <sub>CC</sub> –2   |      |      | 0 to V <sub>CC</sub> –2   |      |      |      |
| V <sub>OH</sub>                  | High-level output voltage                                            | R <sub>L</sub> = 2 kΩ                                                                           | 25°C             | V <sub>CC</sub> –1.5      |      |      | V <sub>CC</sub> –1.5      |      |      |                           |      |      | V    |
|                                  |                                                                      | R <sub>L</sub> = 10 kΩ                                                                          | 25°C             |                           |      |      |                           |      |      | V <sub>CC</sub> –1.5      |      |      |      |
|                                  |                                                                      | V <sub>CC</sub> = MAX, R <sub>L</sub> = 2 kΩ                                                    | Full range       | 26                        |      |      | 26                        |      |      | 22                        |      |      |      |
|                                  |                                                                      | V <sub>CC</sub> = MAX, R <sub>L</sub> ≥ 10 kΩ                                                   | Full range       | 27 28                     |      |      | 27 28                     |      |      | 23 24                     |      |      |      |
| V <sub>OL</sub>                  | Low-level output voltage                                             | R <sub>L</sub> ≤ 10 kΩ                                                                          | Full range       | 5 20                      |      |      | 5 20                      |      |      | 5 20                      |      |      | mV   |
| A <sub>VD</sub>                  | Large-signal differential voltage amplification                      | V <sub>CC</sub> = 15 V, V <sub>O</sub> = 1 V to 11 V,<br>R <sub>L</sub> = ≥ 2 kΩ                | 25°C             | 50                        | 100  |      | 25                        | 100  |      | 100                       |      |      | V/mV |
|                                  |                                                                      |                                                                                                 | Full range       | 25                        |      |      | 15                        |      |      | 15                        |      |      |      |
| CMRR                             | Common-mode rejection ratio                                          | V <sub>IC</sub> = V <sub>ICRmin</sub>                                                           | 25°C             | 70                        | 80   |      | 65                        | 80   |      | 50                        | 80   |      | dB   |
| k <sub>SVR</sub>                 | Supply-voltage rejection ratio (ΔV <sub>CC</sub> /ΔV <sub>IO</sub> ) |                                                                                                 | 25°C             | 65                        | 100  |      | 65                        | 100  |      | 50                        | 100  |      | dB   |
| V <sub>O1</sub> /V <sub>O2</sub> | Crosstalk attenuation                                                | f = 1 kHz to 20 kHz                                                                             | 25°C             | 120                       |      |      | 120                       |      |      | 120                       |      |      | dB   |
| I <sub>O</sub>                   | Output current                                                       | V <sub>CC</sub> = 15 V, V <sub>ID</sub> = 1 V,<br>V <sub>O</sub> = 0                            | 25°C             | –20                       | –30  | –60  | –20                       | –30  | –60  | –20                       | –30  | –60  | mA   |
|                                  |                                                                      |                                                                                                 | Full range       | –10                       |      |      | –10                       |      |      | –10                       |      |      |      |
|                                  |                                                                      | V <sub>CC</sub> = 15 V, V <sub>O</sub> = 15 V                                                   | 25°C             | 10                        | 20   |      | 10                        | 20   |      | 10                        | 20   |      |      |
|                                  |                                                                      |                                                                                                 | Full range       | 5                         |      |      | 5                         |      |      | 5                         |      |      |      |
|                                  |                                                                      | V <sub>ID</sub> = –1 V, V <sub>O</sub> = 200 mV                                                 | 25°C             | 12                        | 30   |      | 12                        | 30   |      | 30                        |      |      | μA   |
| I <sub>OS</sub>                  | Short-circuit output current                                         | V <sub>CC</sub> at 5 V, GND at –5 V, V <sub>O</sub> = 0,                                        | 25°C             |                           | ±40  | ±60  |                           | ±40  | ±60  |                           | ±40  | ±60  | mA   |
| I <sub>CC</sub>                  | Supply current (four amplifiers)                                     | V <sub>O</sub> = 2.5 V, No load                                                                 | Full range       | 0.7 1.2                   |      |      | 0.7 1.2                   |      |      | 0.7 1.2                   |      |      | mA   |
|                                  |                                                                      | V <sub>CC</sub> = MAX, V <sub>O</sub> = 0.5 V <sub>CC</sub> , No load                           | Full range       | 1.4 3                     |      |      | 1.4 3                     |      |      | 1.4 3                     |      |      |      |

† All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified. MAX  $V_{CC}$  for testing purposes is 26 V for LM2902, 30 V for the others.

‡ Full range is –55°C to 125°C for LM124, –25°C to 85°C for LM224, 0°C to 70°C for LM324, and –40°C to 125°C for LM2902.

§ All typical values are at  $T_A = 25^\circ\text{C}$ .

## LM124, LM124A, LM224, LM224A

## LM324, LM324A, LM2902

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electrical characteristics at specified free-air temperature,  $V_{CC} = 5\text{ V}$  (unless otherwise noted) (continued)

| PARAMETER                        |                                                                      | TEST CONDITIONS†                                                                                 | T <sub>A</sub> ‡ | LM124A                    |      |      | LM224A                    |      |      | LM324A                    |      |      | UNIT |
|----------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|------------------|---------------------------|------|------|---------------------------|------|------|---------------------------|------|------|------|
|                                  |                                                                      |                                                                                                  |                  | MIN                       | TYP§ | MAX  | MIN                       | TYP§ | MAX  | MIN                       | TYP§ | MAX  |      |
| V <sub>IO</sub>                  | Input offset voltage                                                 | V <sub>CC</sub> = 5 V to 30 V,<br>V <sub>IC</sub> = V <sub>ICRmin</sub> , V <sub>O</sub> = 1.4 V | 25°C             |                           |      | 2    |                           | 2    | 3    |                           | 2    | 3    | mV   |
|                                  |                                                                      |                                                                                                  | Full range       |                           |      | 4    |                           |      | 4    |                           |      | 5    |      |
| I <sub>IO</sub>                  | Input offset current                                                 | V <sub>O</sub> = 1.4 V                                                                           | 25°C             |                           |      | 10   |                           | 2    | 15   |                           | 2    | 30   | nA   |
|                                  |                                                                      |                                                                                                  | Full range       |                           |      | 30   |                           |      | 30   |                           |      | 75   |      |
| I <sub>IB</sub>                  | Input bias current                                                   | V <sub>O</sub> = 1.4 V                                                                           | 25°C             |                           |      | –50  |                           | –15  | –80  |                           | –15  | –100 | nA   |
|                                  |                                                                      |                                                                                                  | Full range       |                           |      | –100 |                           |      | –100 |                           |      | –200 |      |
| V <sub>ICR</sub>                 | Common-mode input voltage range                                      | V <sub>CC</sub> = 30 V                                                                           | 25°C             | 0 to V <sub>CC</sub> –1.5 |      |      | 0 to V <sub>CC</sub> –1.5 |      |      | 0 to V <sub>CC</sub> –1.5 |      |      | V    |
|                                  |                                                                      |                                                                                                  | Full range       | 0 to V <sub>CC</sub> –2   |      |      | 0 to V <sub>CC</sub> –2   |      |      | 0 to V <sub>CC</sub> –2   |      |      |      |
| V <sub>OH</sub>                  | High-level output voltage                                            | R <sub>L</sub> = 2 kΩ                                                                            | 25°C             | V <sub>CC</sub> –1.5      |      |      | V <sub>CC</sub> –1.5      |      |      | V <sub>CC</sub> –1.5      |      |      | V    |
|                                  |                                                                      | V <sub>CC</sub> = 30 V, R <sub>L</sub> = 2 kΩ                                                    | Full range       | 26                        |      |      | 26                        |      |      | 26                        |      |      |      |
|                                  |                                                                      | V <sub>CC</sub> = 30 V, R <sub>L</sub> ≥ 10 kΩ                                                   | Full range       | 27                        |      |      | 27 28                     |      |      | 27 28                     |      |      |      |
| V <sub>OL</sub>                  | Low-level output voltage                                             | R <sub>L</sub> ≤ 10 kΩ                                                                           | Full range       | 20                        |      |      | 5 20                      |      |      | 5 20                      |      |      | mV   |
| A <sub>VD</sub>                  | Large-signal differential voltage amplification                      | V <sub>CC</sub> = 15 V, V <sub>O</sub> = 1 V to 11 V, R <sub>L</sub> = ≥2 kΩ                     | Full range       | 25                        |      |      | 25                        |      |      | 15                        |      |      | V/mV |
| CMRR                             | Common-mode rejection ratio                                          | V <sub>IC</sub> = V <sub>ICRmin</sub>                                                            | 25°C             | 70                        |      |      | 70 80                     |      |      | 65 80                     |      |      | dB   |
| k <sub>SVR</sub>                 | Supply-voltage rejection ratio (ΔV <sub>CC</sub> /ΔV <sub>IO</sub> ) |                                                                                                  | 25°C             | 65                        |      |      | 65 100                    |      |      | 65 100                    |      |      | dB   |
| V <sub>O1</sub> /V <sub>O2</sub> | Crosstalk attenuation                                                | f = 1 kHz to 20 kHz                                                                              | 25°C             | 120                       |      |      | 120                       |      |      | 120                       |      |      | dB   |
| I <sub>O</sub>                   | Output current                                                       | V <sub>CC</sub> = 15 V, V <sub>ID</sub> = 1 V, V <sub>O</sub> = 0                                | 25°C             | –20                       |      |      | –20 –30 –60               |      |      | –20 –30 –60               |      |      | mA   |
|                                  |                                                                      |                                                                                                  | Full range       | –10                       |      |      | –10                       |      |      | –10                       |      |      |      |
|                                  |                                                                      | V <sub>CC</sub> = 15 V, V <sub>O</sub> = 15 V                                                    | 25°C             | 10                        |      |      | 10 20                     |      |      | 10 20                     |      |      |      |
|                                  |                                                                      |                                                                                                  | Full range       | 5                         |      |      | 5                         |      |      | 5                         |      |      |      |
|                                  |                                                                      | V <sub>ID</sub> = –1 V, V <sub>O</sub> = 200 mV                                                  | 25°C             | 12                        |      |      | 12 30                     |      |      | 12 30                     |      |      | μA   |
| I <sub>OS</sub>                  | Short-circuit output current                                         | V <sub>CC</sub> at 5 V, V <sub>O</sub> = 0, GND at –5 V                                          | 25°C             | ±40 ±60                   |      |      | ±40 ±60                   |      |      | ±40 ±60                   |      |      | mA   |
| I <sub>CC</sub>                  | Supply current (four amplifiers)                                     | V <sub>O</sub> = 2.5 V, No load                                                                  | Full range       | 0.7 1.2                   |      |      | 0.7 1.2                   |      |      | 0.7 1.2                   |      |      | mA   |
|                                  |                                                                      | V <sub>CC</sub> = 30 V, V <sub>O</sub> = 15 V, No load                                           | Full range       | 1.4 3                     |      |      | 1.4 3                     |      |      | 1.4 3                     |      |      |      |

<sup>†</sup> All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified.<sup>‡</sup> Full range is –55°C to 125°C for LM124A, –25°C to 85°C for LM224A, and 0°C to 70°C for LM324A.<sup>§</sup> All typical values are at  $T_A = 25^\circ\text{C}$ .

operating conditions,  $V_{CC} = \pm 15\text{ V}$ ,  $T_A = 25^\circ\text{C}$

| PARAMETER |                                | TEST CONDITIONS                                                                             | TYP | UNIT                         |
|-----------|--------------------------------|---------------------------------------------------------------------------------------------|-----|------------------------------|
| SR        | Slew rate at unity gain        | $R_L = 1\text{ M}\Omega$ , $C_L = 30\text{ pF}$ , $V_I = \pm 10\text{ V}$<br>(see Figure 1) | 0.5 | $\text{V}/\mu\text{s}$       |
| $B_1$     | Unity-gain bandwidth           | $R_L = 1\text{ M}\Omega$ , $C_L = 20\text{ pF}$ (see Figure 1)                              | 1.2 | MHz                          |
| $V_n$     | Equivalent input noise voltage | $R_S = 100\text{ }\Omega$ , $V_I = 0\text{ V}$ , $f = 1\text{ kHz}$<br>(see Figure 2)       | 35  | $\text{nV}/\sqrt{\text{Hz}}$ |

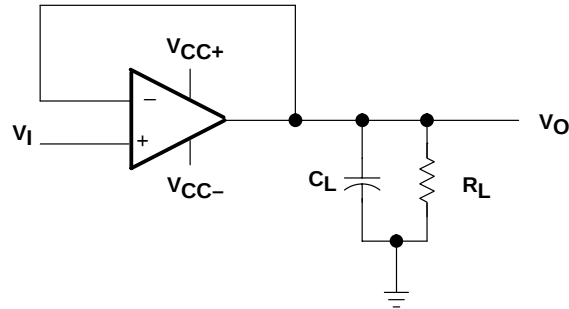


Figure 1. Unity-Gain Amplifier

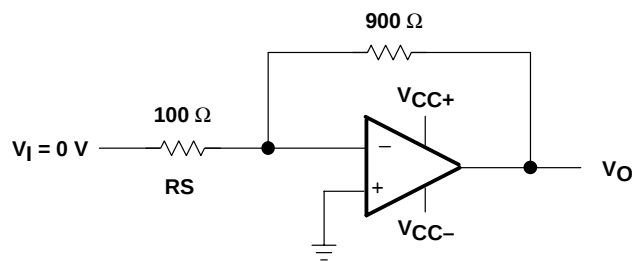


Figure 2. Noise-Test Circuit

## **IMPORTANT NOTICE**

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